การประเมินการกัดเซาะพื้นท้องทะเลโดยการสำรวจไซด์สแกนโซน่าร์ในพื้นที่ชายฝั่งหาดโคลน
ปากแม่น้ำเจ้าพระยา ประเทศไทย

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EVALUATING SEABED EROSION BY SIDE-SCAN SONAR SURVEY
IN MUDDY COAST OF CHAO PHRAYA RIVER MOUTH, THAILAND

Miss Rujiporn Suthisanonth



A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Earth Sciences
Department of Geology
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รุจิภร สุทธิสานนท์ : การประเมินการกัดเซาะพื้นท้องทะเลโดยการสำรวจไซด์สแกนโซน่าร์ในพื้นที่ชายฝั่งหาดโคลน ปากแม่น้ำเจ้าพระยา ประเทศไทย (EVALUATING SEABED EROSION BY SIDE-SCAN SONAR SURVEY IN MUDDY COAST OF CHAO PHRAYA RIVER MOUTH, THAILAND) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ธนวัฒน์ จารุพงษ์สกุล{, 94 หน้า.

พื้นที่ชายฝั่งทะเลบริเวณอ่าวไทยตอนบนเป็นพื้นที่หาดเลนที่มีสภาพเป็นดินอ่อนซึ่งง่ายต่อการถูกกัดเซาะ พื้นที่เหล่านี้มีอัตราการกัดเซาะชายฝั่งที่รุนแรงที่สุดของประเทศ อีกทั้งสภาพปัญหาแผ่นดินทรุดบริเวณชายฝั่งทะเลอ่าวไทยตอนบนในเขตกรุงเทพมหานครและปริมณฑล และการเพิ่มสูงขึ้นของระดับน้ำทะเลยังมีส่วนในการเร่งการกัดเซาะ งานวิจัยนี้มีวัตถุประสงค์เพื่อประเมินการกัดเซาะพื้นท้องทะเลในพื้นที่ชายฝั่งหาดโคลน ปากแม่น้ำเจ้าพระยา ประเทศไทย ซึ่งตั้งอยู่บนพื้นที่ชายฝั่งทะเลบริเวณอ่าวไทยตอนบน โดยทำการสำรวจจากชายฝั่งออกไปในทะเลเป็นระยะทาง 12 กม. ที่มีแนวสำรวจ 3 แนว ได้แก่ แนวสำรวจบ้านโคกขาม บ้านขุนสมุทรจีน และบ้านคลองตำหรุ โดยใช้เครื่องมือไซด์สแกนโซน่าร์ในการสำรวจสัณฐานวิทยาของพื้นท้องทะเล และใช้เครื่องมือเอคโค่ซาวเดอร์ประเภทสัญญาณคลื่นความถี่เดี่ยวสำรวจความลึกของท้องทะเล ทำการสำรวจในปี พ.ศ. 2555 โดยทำการเปรียบเทียบกับภาพตัดขวางของพื้นท้องทะเลที่ได้จากข้อมูลแผนที่เดินเรือ กรมอุทกศาสตร์ ในช่วงปี พ.ศ. 2503 จนถึงปี พ.ศ. 2555 นอกจากนี้ได้ทำการเก็บตัวอย่างตะกอนบนพื้นท้องทะเลมาทำการวิเคราะห์ ได้แก่ การตรวจหาปริมาณน้ำในตัวอย่าง การตรวจวัดการกระจายตัวของขนาดอนุภาคด้วยเทคนิคกระเจิงของแสง และการตรวจหาปริมาณซีเซียม-137 ที่มีในตัวอย่างด้วยวิธีการส่งผ่านรังสีแกมม่า จากผลการเปรียบเทียบภาพตัดขวางของพื้นท้องทะเลพบว่าการเปลี่ยนแปลงพื้นท้องทะเลในพื้นที่ศึกษาเกิดขึ้นอย่างช้า ๆ โดยในช่วงระยะเวลาไม่เกิน 4 ปี พบว่ามีการเปลี่ยนแปลงเพียงเล็กน้อยจนแทบจะไม่มีการเปลี่ยนแปลง แต่การเปลี่ยนแปลงพื้นท้องทะเลจะเห็นได้ชัดในช่วงระยะเวลายาวนานในรอบ 10 ปี ผลจากภาพโซโนกราฟแสดงให้เห็นว่าลักษณะพื้นท้องทะเลประกอบไปด้วยวัตถุอ่อนนุ่ม จากผลการตรวจหาปริมาณน้ำในตัวอย่างพบว่าน้ำในตัวอย่างมีปริมาณลดลงในระดับชั้นดินที่ลึกขึ้น และปริมาณน้ำเพิ่มสูงขึ้นในระยะทางที่ไกลออกไปนอกชายฝั่ง จากผลการศึกษาการกระจายตัวของขนาดอนุภาค พบว่าอนุภาคตะกอนส่วนใหญ่บนพื้นท้องทะเลในพื้นที่บ้านโคกขามและบ้านขุนสมุทรจีนประกอบไปด้วยอนุภาคดินเหนียวและทรายแป้ง ขณะที่อนุภาคตะกอนส่วนใหญ่ในพื้นที่บ้านคลองตำหรุประกอบไปด้วยอนุภาคทราย และจากผลการตรวจวัดปริมาณซีเซียม-137 ในตัวอย่าง พบว่าตะกอนที่อยู่ใกล้ชายฝั่งมีปริมาณซีเซียม-137 ต่ำ ซึ่งแสดงให้เห็นว่าเป็นบริเวณที่เกิดการกัดเซาะ ขณะที่ตะกอนที่อยู่ไกลออกไปนอกชายฝั่ง พบว่ามีปริมาณซีเซียม-137 สูงขึ้น ผลการศึกษาทั้งหมดแสดงให้เห็นว่าพื้นท้องทะเลในพื้นที่ศึกษามีการกัดเซาะบริเวณใกล้ชายฝั่ง และมีการสะสมตัวของตะกอนบริเวณนอกชายฝั่ง



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# # 5472245023 : MAJOR EARTH SCIENCES
KEYWORDS: SEABED EROSION / SIDE-SCAN SONAR / MUDDY COAST / BATHYMETRY / CS-137

RUJIPORN SUTHISANONTH: EVALUATING SEABED EROSION BY SIDE-SCAN SONAR SURVEY IN MUDDY COAST OF CHAO PHRAYA RIVER MOUTH, THAILAND. ADVISOR: PROF. THANAWAT JARUPONGSAKUL, Ph.D.{, 94 pp.

The muddy coasts of the Upper Gulf of Thailand (UGOT) are very sensitive to coastal erosion. These areas have the most severe erosion rate in Thailand. Moreover, this erosion has also been enhanced by land subsidence in Bangkok area and vicinity as well as the sea level rise. This study aims to assess the seafloor erosion in muddy coasts of the UGOT near the Chao Phraya River mouth. The survey was done from the coast to 12 km offshore in three survey lines, Ban Khok Kam, Ban Khun Samut Chin, and Ban Klong Tamru survey lines. Side-scan sonar was used as a tool to investigate the seafloor morphology and single-beam echo sounder was used as a tool to determine the bathymetry. The bathymetric profiles surveyed on 2012 by this study were also compared with those surveyed by Hydrographic Department, Royal Thai Navy (HDRTN) from 1960 onwards. Furthermore, the sediment samples were collected to determine the water content, the laser diffraction method was applied to investigate the particle-size distribution, and the erosion of the seafloor was verified by Cesium-137 (Cs-137) concentration. The comparison among the bathymetric profiles shows an extreme change on the seafloor in the long time scale, approximately 10 years. However, in the short time scale or no more than 4 years, the change cannot be seen obviously. The results of sonographs suggest that most of the sediments on the seafloor are soft materials. The results of water content in the sediments are lower in the deeper layers but higher in the farther offshore areas. The results of particle-size distribution reveal that most of sediments in Ban Khok Kam and Ban Khun Samut Chin are clay and silt while most of that in Ban Klong Tamru is sand. The Cs-137 concentrations show low value in the sediments collected near the coast while the sediments collected far away from the coast have higher values. In conclusions, it is suggested that the sediments are eroded near the coast and redeposited in the offshore area.



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| Field of Study: | Earth Sciences | Advisor's Signature | ..................................... |
| Academic Year: | 2014 | | |

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CONTENTS

Page

# LIST OF TABLES

Page

# LIST OF FIGURES

Page

Page

# CHAPTER I

# INTRODUCTION

## 1.1 Rationale

The coastal areas of the Upper Gulf of Thailand (UGOT) from the Bang Pakong Estuary to the Phetchaburi Estuary are very sensitive to coastal erosion. These areas have the most severe erosion rate in Thailand during 1960 – 2008, about 35 years, with the erosion rate of up to 30 meters per year on a distance of 82 kilometers along the coast, and the total areas of 18,594 acres was eroded (Jarupongsakul et al. (2008)). In the next 20 years, the coastal erosion rate in some areas can reach 65 to 85 meters per year (Jarupongsakul et al. (2008)). Moreover, the coastal erosion has also been enhanced by land subsidence in the coastal areas of the UGOT (i.e. Bangkok area and nearby provinces) (Brand and Paveenchana (1971; Teartisup and Kerdsueb (2013)) and the sea level rise. If no measure is applied to solve this issue within 20 years from now, the lost from the coastal erosion can be up to 1.3 kilometers and in the next 50 and 100 years, the lost can be up to 2.3 and 6.5 kilometers, respectively. The effects of this crisis within these areas will directly impact the economy, the resource and the society as a whole of Thailand. Human activities, in particular, coastal resources management, tourism promotion and the preservation of natural ecosystems are related to the living conditions and livelihood of coastal communities in these areas in both direct and indirect ways (Jarupongsakul et al. (2008)). The problem is known as the silent disaster that occurs while people are unaware but permanently affects the area in the long term. Unlike the other disasters, such as floods, landslides, earthquakes, etc., when these disasters occur, people are usually aware. As a result, the awareness of the coastal erosion should be raised.

In particular, Ban Khun Samut Chin, Samut Prakarn Province in Thailand is the community facing the severe erosion problem. This area has been surrounded by the sea due to coastal erosion. Many of the families who lived in Ban Khun Samut Chin village have moved their houses inland four to five times during the last two generations. In total, over a kilometer of land has been lost and the further four kilometers have been affected (Jarupongsakul (2010)).

The seafloor erosion of the UGOT was studied by Jarupongsakul (2010). The research used single-beam echo-sounding for surveying in three lines, at Ban Khun Samut Chin, Ban Khok Kam, and Ban Klong Tamru from the coast to 12 km offshore. The bathymetric profile in 2010 was derived and compared with the bathymetric profiles in the year 2008 and 1960 according to the nautical maps from the Hydrographic Department, Royal Thai Navy (HDRTN). According to this research, there was almost no difference between the bathymetric profiles in 2008 and 2010 while the difference between those in 1960 and 2008 was obvious.

This study aims to study the seafloor erosion in the intertidal area in these three survey lines (Figure 1) by investigating the seafloor morphology, comparing the bathymetric profiles from 1960 to 2012, and evaluating the relationship between the bathymetric profiles and coastal erosion in this area.

## 1.2 Objectives

1. To study the seafloor morphology in the muddy coast of the Chao Phraya River mouth, Thailand by side-scan sonar survey
2. To study the depth of the sea and the seafloor level change by echo-sounding survey and compare the bathymetric profiles during 1960 to 2012
3. To determine the relationship between the bathymetric profile and coastal erosion in the study area

## 1.3 Scopes

1. This study focuses on the intertidal area in the UGOT in 3 survey lines (from the coast to 12 km offshore) as follows;
    1. Survey line at Ban Khok Kam, Samut Sakhon Province
    2. Survey line at Ban Khun Samut Chin, Samut Prakarn Province
    3. Survey line at Ban Klong Tamru, Samut Prakarn Province

   Moreover, the area of 10 $km^2$ around the middle of Ban Khun Samut Chin survey line was studied seafloor morphology in detail.
2. The surveys were conducted during the northeast (NE) monsoon season.
3. Sediment samplings were done at every 2 km in the 3 survey lines.

## 1.4 Expected outcomes

1. The seafloor morphology in muddy coasts of study area is known.
2. The bathymetric profiles and the bathymetric maps of the study area are derived.
3. The areas of erosion in muddy coast of study area are determined.
4. The particle-size distribution at each sampling points of the study area is derived.

# CHAPTER II

# LITERATURE REVIEWS

## 2.1 The Study Area

The study area covers the intertidal area of the UGOT from the longitudes of 100°20’0’’ to 100°40’0’’E and the latitude of 13°20’0’’ to 13°30’0’’N. The northern boundary of the study area is the coastline while other sides are open to the sea. The water depth increases gradually from north to south, with gradients of less than 1/1000, to the maximum depth of about 25 – 30 m (MSL) in the southern boundary (Uehara et al. (2010)). Depths exceeding 30 m are found only in a few areas in the southeastern UGOT. The seafloor of the UGOT at latitude of 13°20’N is covered by clay sediments, and the northern coast of the UGOT is fringed by mud flats. The width of the intertidal zone is generally 1 – 2 km, but it is as wide as 8 km at the mouth of the Chao Phraya (CP) River (Uehara et al. (2010)). The UGOT is in the Southwest Asian monsoon and Northeast monsoon climate zone. Northeasterly wind prevails from mid-October to January (dry or northeast monsoon season), whereas southwesterly wind is dominant from May to early October (wet or southwest monsoon season). Wind blows mainly from the south during the transitional period from late January or early February to April. Strong winds from east or west are hindered by mountain ranges that are parallel to the eastern and western coasts of the UGOT (Uehara et al. (2010)). The location of the study area is shown in Figure 1.

Three survey lines with the length of around 12 km from the coast as shown in Figure 1 were used to represent the study area. These lines are as follows;

1. Survey line at Ban Khok Kam, Samut Sakhon Province
2. Survey line at Ban Khun Samut Chin, Samut Prakarn Province
3. Survey line at Ban KlongTamru, Samut Prakarn Province

Moreover, the area of 10 $km^2$ around the middle of the survey line at Ban Khun Samut Chin was used as the area where the seafloor morphology was studied in detail.

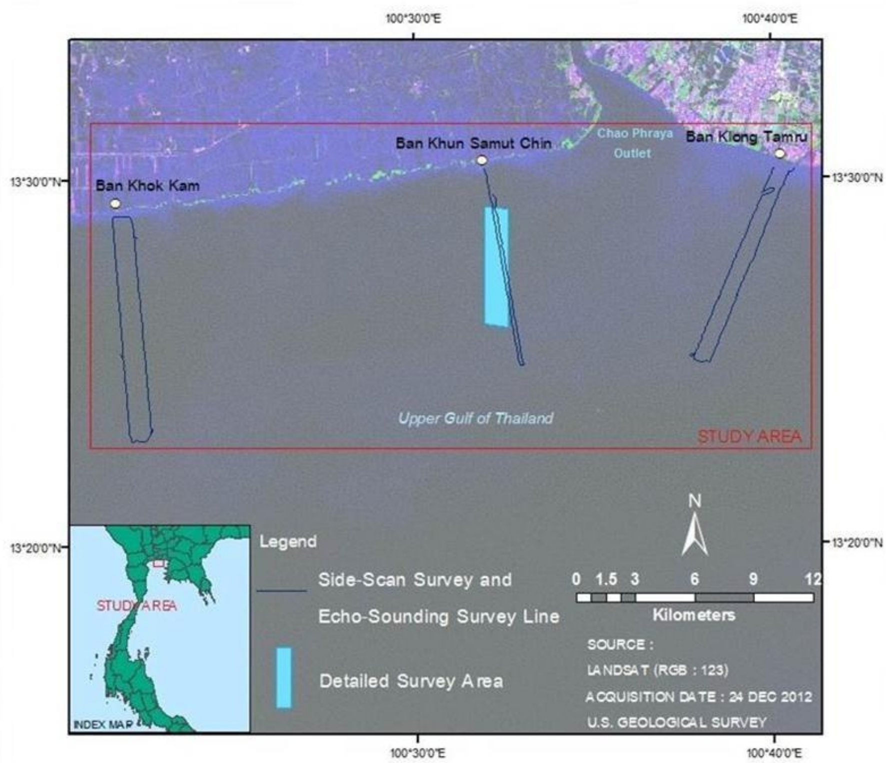


**Figure 1** Location of the study area (Suthisanonth et al. (2015)).



## 2.2 The Study of Coastal Erosion in the Study Area

Ban Khok Kam and Ban Khun Samut Chin are located on the western side of the Chao Phraya River mouth in Samut Sakhon Province and Samut Prakarn Province, respectively. Ban Klong Tamru is located on the eastern side of the Chao Phraya River mouth in Samut Prakarn Province. The geomorphology of these areas are tidal delta with tidal flat where sediments were brought down from the river (Uehara et al. (2010)). The coastal areas have experienced the severe coastal erosion in the last three decades (Saito et al. (2007)). At Ban Khun Samut Chin, the area with the highest erosion rate (see Figure 2), it was estimated that about 60.8 $km^2$ will be lost in the next 20 year if no action has been done to protect the coast (Saito et al. (2007)).

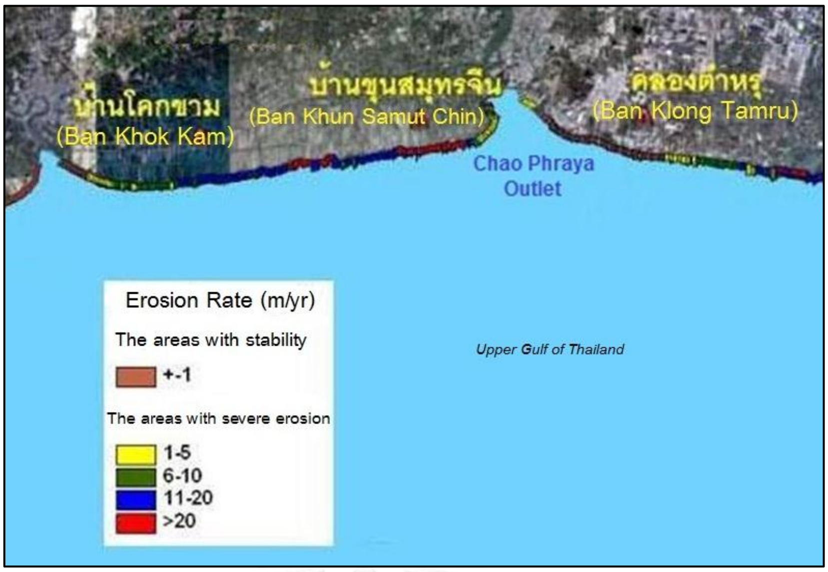


**Figure 2** The erosion rate of three locations (Ban Khok Kam, Ban Khun Samut Chin and Ban Klong Tamru) (Jarupongsakul (2010)).

The inner part of the UGOT has been experiencing coastal recession for the past 30 years due to various causes such as sea level rise, land subsidence, wind, wave, storm wave, dwindle sediment supplies and misuse of coastal land (Saito et al. (2007)). It is currently found that the 82 kilometers of mudflat shorelines, along the five coastal provinces which are Samut Songkram, Samut Sakhon, Bangkok, Samut Prakarn and Chachaengsao have been severely eroded in the past decades (Jarupongsakul (2010)). Many types of coastal protection structures such as seawall, stone mound, mangrove replanting, etc. have been built to alleviate the problem, but it was found that these structures could not stop the coastal erosion (Saito et al. (2007)).

Building the disintegrated wave-power barrier consisting of three rows of triangular concrete poles to solve this problem was studied by Jarupongsakul et al. (2008). This barrier was constructed at about 500 m offshore of Wat Khun Samut Chin and the space between each row was 1.5 m. Physical conditions of water mass, wave condition and sedimentation in front and behind the barrier were observed and analyzed. The result showed that the barrier can reduce the wave energy and lead to sediment accumulation behind the barrier. Sedimentation rate varied with changing wind direction upon the monsoon condition in the area.

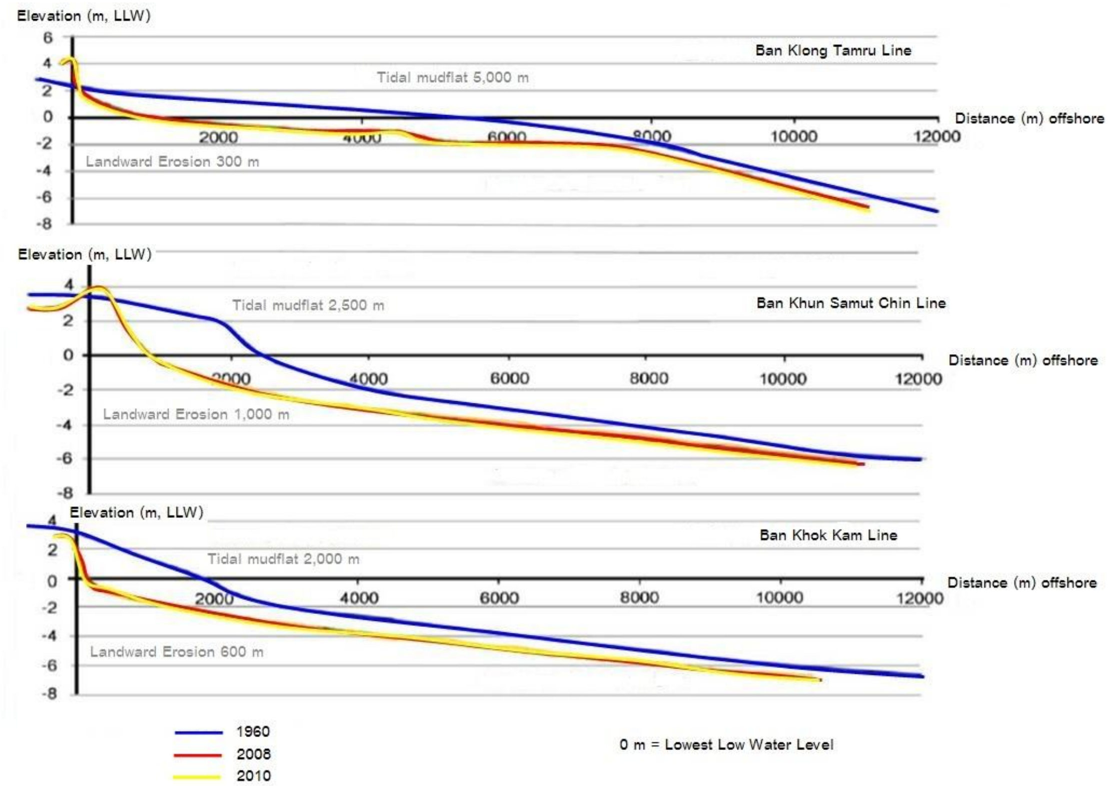


**Figure 3** Bathymetric profiles of three survey lines (Jarupongsakul (2010)).



According to Figure 3, the seafloor erosion of the UGOT was studied by Jarupongsakul (2010). The research using echo sounding method for surveying all three lines from the coast to 12 km offshore. The data from echo-sounding surveys (the water depths) were recorded every second and the coordinates were recorded by GPS. The first survey line was at Ban Klong Tamru, Samut Prakarn Province. The second one was at Ban Khun Samut Chin, Samut Prakarn Province. The third one was at Ban Khok Kam, Samut Sakhon Province.

The bathymetric profiles from three survey lines in 2008 and 2010 compared with the 1960 profile according to the nautical maps of HDRTN reveal that from 1960 to 2008 (48 years), the seafloor at Ban Klong Tamru survey line was eroded for about 2 m. In 1960, the muddy coast when the tide was at the lowest was about 5 km wide while in 2008, it was about 1 km wide. Hence, seafloor erosion causes the muddy coast at Ban Klong Tamru being shortened for about 4 km during these 48 years. At Ban Khun Samut Chin survey line, the seafloor was eroded for about 4 m and the muddy coast was shortened for about 1.5 km during these 48 years, and at Ban Khok Kam survey line, the seafloor was eroded for about 2 m and the muddy coast was shortened for about 1.75 km during the same period. The coastline when the tide was at the lowest was only about 250 m wide (Jarupongsakul (2010)).

Comparative data of the seafloor from the three survey lines between 2008 and 2010 shows only slight change over Ban Klong Tamru line, from 5 to 12 km offshore in Ban Khun Samut Chin line, and from the coast to 1 km offshore in Ban Khok Kam line. According to the survey, the seafloor was gradually shortened, since there was almost no difference between the bathymetric profiles in 2008 and 2010 while the difference between those in 1960 and 2008 was obvious. However, the change might not be normal if there had been an abnormal situation such as storm or flood. These situations might cause the unexpected change on the seafloor. From the profiles of three survey lines between 2008 and 2010, the change of the seafloor was found from the coast to 3 km offshore. Hence, it was believed that pumping the sediments from 3 km offshore or further should not affect the coastal erosion. As a result, filling the sediments in the coastal area by the sediments from 3 km offshore or further could be considered as a measure to handle the problem of coastal erosion (Jarupongsakul (2010)).

**2.3 The Oceanography of the Gulf of Thailand**

The Gulf of Thailand is characterized as an estuary of drowned river valley with the seabeds which was once emerged above sea surface. On the sea bottom, there are ancient deep channels connected to present rivers such as Mae Klong River, Bang Pakong River, Chantaburi River etc. The fresh water from four major rivers, Mae Klong, Thachin, Chao Phraya, and Bang Pakong, all flow into the UGOT, meanwhile, the gulf is also supported by minor rivers from the east and west parts of Thailand. Hence, the Gulf of Thailand is the basin of deposited sediments from those rivers. Based on the surveys of the Hydrographic Department, Royal Thai Navy, it is indicated that sandy mud or mud appears at the center of the gulf while some parts in the Western Gulf of Thailand are covered by sandy mud, muddy sand, and sand. The details on the oceanography of Thailand's coast are as follows (DMCR (2013)):

### 2.3.1 Depth of the seabed

A pan-like shape seabed of the Gulf of Thailand has the deepest point with the depth of about 80 m (MSL) and has the main deep channel with the depth of more than 50 m (MSL) in the middle of the gulf. The UGOT is the northern part of the Gulf of Thailand with an inverted U-shape covering the area of approximately 100 × 100 $km^2$. The deepest point of the UGOT is in the eastern part with the depth of about 40 m (MSL) while the western part is more shallow with the depth of about 15 m (MSL). The Gulf of Thailand is split from the South China Sea by two underwater ridges. The first ridge stretches south-eastward from Khota Bharu in Malaysia for 160 km with the average depth of 50 m (MSL). The second ridge stretches south-westward from Cape Camou in Vietnam for about 100 km with a sill depth of about 67 m (MSL). Moreover, there is an underwater sill that acts as a hydraulic controller of current flow in the lower Gulf of Thailand (DMCR (2013)).

### 2.3.2 Current

The ocean current is generated by the sea surface wind because the surface wind can produce a movable layer of water mass which is called Ekman layer (50 m of the Ekman layers are generally found in oceans and 30 – 40 m are found in the Gulf of Thailand), and the movement of the water mass is called Ekman transport. Theoretically, in the northern hemisphere, the layer of water mass from the surface is moved with the angle of 45 degrees to the right of the surface wind and the angle is increasing in the deeper layer until they reach the bottom of the Ekman layer, the net transportation of water mass is at the angle of 90 degrees to the right of the surface wind. That means at this point, the direction of the wind is totally opposite to the movement of water mass.

The current generated by rivers, which produce gravitational circulation is the freshwater discharged from the rivers and suspended in the upper layer because of the lower density of freshwater, while the high density saline water is at the lower layer. The mixing of both fresh and saline water is influenced by currents and waves. Generally, the salinity in the Gulf of Thailand is extremely affected by freshwater discharge but the impact of salinity on variation of current circulation in the Gulf of Thailand is not significant because the annual volumes of the freshwater discharged into the gulf is very small in comparison to the total quantity of water mass in the Gulf of Thailand.

However, the difference of water density causes oceanic circulation in both horizontal and vertical direction. According to the study of Sverdrup, Johnson, and Fleming (1942) cited in DMCR (2013), it was found that oceanic current in the northern hemisphere flows perpendicularly to the slope of the density of water surface with the lower density water on the right (DMCR (2013)).



### 2.3.3 Tide

Diurnal tide cycle is mostly found in the Gulf of Thailand where only one high and one low tide occur in each day. Since the Gulf of Thailand is shallow with rough seabeds, the movement of tidal waves is not consistent. When the waves approach the shorelines, they will move back to the sea again and interfere other waves. As the results, only single low tide and single high tide are remained in each day. For the UGOT and some locations experience a mixed tide where there are two uneven tides a day, or sometimes, one high tide and one low tide in each day are occurred. The high and low tides reported by the Tidal Monitoring Station of

Hydrographic Department, Royal Thai Navy at Ko Prab, Surat Thani Province were about 2.9 and 0.32 m (MSL), respectively. The tidal range was 2.61 m (DMCR (2013)).

2.3.4 Wave

The generation of waves in the Gulf of Thailand is influenced by monsoon, the northeast monsoon produces the larger waves in the western part of the Gulf of Thailand, and the southwest monsoon produces the larger wave in the eastern part. The waves in the UGOT are not very large because the southwest monsoon is mild and occurred in a short period. Generally, the waves in the Gulf of Thailand are small with the average height of 1 – 2 m. Wave period should be considered to address the impact of waves on shorelines, for example, the impacts of a small wave with long period are higher than the impacts of a large wave with short period (DMCR (2013)).

## 2.4 Applications of Side-Scan Sonar

Side-scan sonar (SSS) has been defined as an acoustic imaging device used to provide wide-area, high-resolution pictures of the seabed (Savini (2011)). This technique was developed by Professor Harold Edgerton and his team in the 1960s during World War II to detect submarines. Its first applications mainly pertained to the search for objects on the seabed, subsequent works have led to far-reaching advances in the use of sonar in marine geophysics and geology (Savini (2011)). Due to its capacity to provide seabed images, SSS has become an instrumental tool in seafloor mapping, with a number of applications, such as:

- Investigation of seafloor morphology and sediment characteristics (i.e. occurrence of reliefs, depressions, sedimentary structures etc.)
- Mapping the distribution of marine sediments and even peculiar biocenosis like seagrass meadows, coral banks etc.

- Monitoring the seafloor for environmental applications, such as coastal and deep environment management.

The underwater environment (current, density, salinity etc.) can considerably impact the data, as well as the operator management of the system. Survey vessel course, transducers speed, tow fish altitude above the seabed and the range setting should be determined upon the quality of the sonar data, according to the aim of the survey (Savini (2011)).

The SSS system is designed to image the seafloor by transmitting sound energy and analyzing the returning signal or echo that bounces back from the seafloor or from submerged objects. A towfish transmits energy in a fan shape to both sides of the track line. The fan width varies with the frequency of the sonar system. Seabed features are characterized by mapping the intensity of reflected returns from different materials. The shape and characteristics of features on the bottom are displayed in gray-scale images called “Sonograph or Sonogram” (Able (1987)). High frequencies such as 500 kHz to 1 MHz give excellent resolutions but the acoustic energy only travels a short distance, therefore the swath or the area of coverage is less (from 50 to 75 m on each side). Lower frequencies such as 50 kHz or 100 kHz give lower resolution but the distance that the energy travels is greatly improved and therefore the area of coverage is much greater (250 m or more on each side) (Fish and Carr (2002)).

SSSs use a swath of sound to indicate the seafloor. They are different from single-beam sounders since they have a much larger footprint shape. However, like single-beam systems, they generate two main types of data, depth (or bathymetry) and backscatter. Traditionally, SSSs provide better backscatter data than depth data. They are often used to create a wide photo realistic image of the seabed (Fish and Carr (2002)).

The acoustic echoes with higher frequency gave a better resolution near the nadir line, and the lower frequency of the echoes returns stronger long-range echos. Georeferenced side-scan sonar images were calculated based on the corrected data, and then combined to side-scan sonar mosaics. The side-scan images were shown in "negative" mode. Acoustically hard materials appeared dark, soft materials appeared bright, and acoustic shadows appeared very bright or white (like photographic negatives). The advantage of the negative mode was that it was easier to perceive dark objects on a bright background. Distinct objects on a background of soft sediments (sand, mud, etc.) were depicted this way (Savini (2011)).

Boss et al. (1999) studied SSS records and bathymetry were used to characterize seafloor type over 470 $km^2$ of the North Carolina inner continental shelf (Oregon Inlet to Kitty Hawk). Five seafloor types were defined by the acoustic characteristics observed on the SSS records (and correlated to sediment types using textural analysis of vibracores). These were: 1) a uniform, light gray sonar record (fine sand); 2) a medium-to-dark-gray sonar record (medium to coarse sand) (See Figure 4); 3) mixed acoustic returns producing a "patchwork" of light gray and medium-to-dark-gray areas (fine sand overlying medium to coarse sand) (See Figure 5); 4) a relatively weak acoustic return with small areas of stronger (darker) reflections producing a "pock-marked" appearance (mud with sands); 5) low-relief scarps evident on the SSS records (eroded compact, cohesive mud).

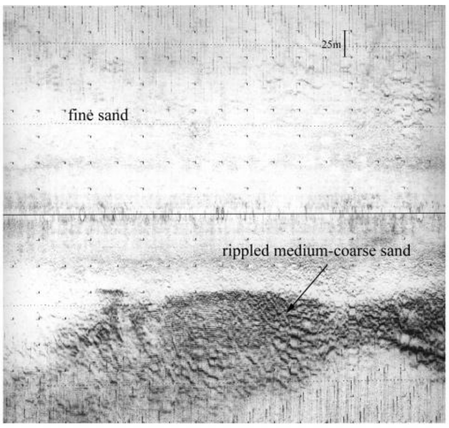


**Figure 4** Sonograph showing light gray (fine sand) and rippled medium to dark gray (medium to coarse sand) (Boss et al. (1999)).

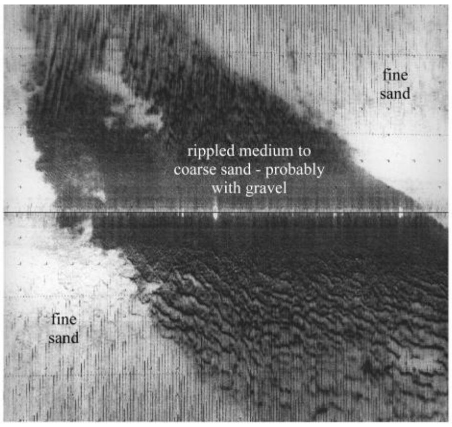


**Figure 5** Sonograph showing rippled dark gray side-scan pattern (medium to coarse sand and gravel) (Boss et al. (1999)).

Caruthers et al. (2004) applied SSS and single-beam echo sounder to investigate seafloor morphology and the bathymetry of the sea, respectively, in the northwest coast near the Kauai Island in Hawaii. This study aimed to compare the frequency of sound waves by using SSS in frequency of 150 and 300 kHz and to compare the depth of water that varied between 2 and 35 m. The results from sonographs found that at the depth of 2 m, the sonograph from the frequency of 300 kHz provided the details of seabed sharper than the sonograph from the frequency of 150 kHz while at the depth of 35 m, the sonograph from the frequency of 150 kHz provided the details of seabed sharper than the sonograph from the frequency of 300 kHz. This research represented that the use of higher frequency made the sonograph clear, but the waves might not travel so far. Therefore, the frequency should be correlated with the depth of water as well.

Lanckneus and Jonghe (2006) presented three case studies of the different areas to analyze the coarse sand and gravel on the seafloor by using multi-beam echo sounder and SSS to investigate the bathymetry and monitor the topographic evolution of the seabed and to map the remaining patches of coarse sand and gravel in order to assist with dredging planning. These area included Lulu Island in Bahrein, Weissebank in Germany and the pathway from Antwerp to Southampton in England where Tricoclor, the vessel carrying vehicles suffered severe damages and went down. The results showed the dark patches which represented a small impressive coral reef at the Lulu Island (See Figure 6), the high coarseness of the sediment at the Weissebank (See Figure 7), and multiple car wrecks from the Tricolor vessel at the pathway from Antwerp to Southampton (See Figure 8). The results of multi-beam echo sounder showed the water depth of the Lulu Island area, Weissebank area and the pathway from Antwerp to Southampton were around 1, 25 and 30 m, respectively.

**Figure 6** Port side-scan sonar channel of a small coral reef; slant range 60 m, distance between white lines: 10m (Lanckneus and Jonghe (2006)).

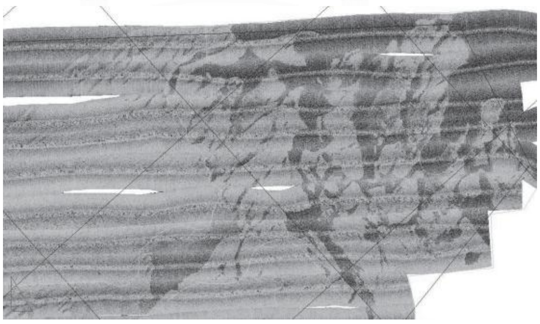

**Figure 7** Section of a side-scan sonar mosaic (approx. 2.5 by 2.5km) recorded on the Weissebank area. The darker patches represent the coarsest sediment (Lanckneus and Jonghe (2006)).

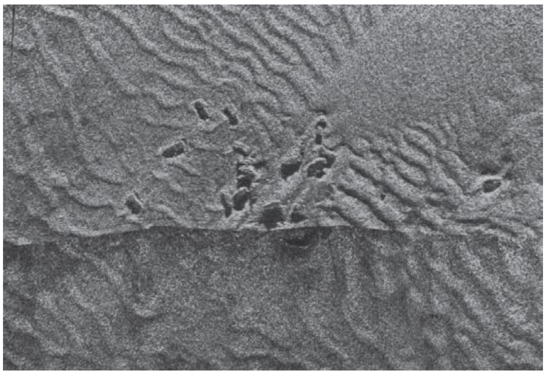

**Figure 8** Fragment of a side-scan sonar mosaic (approx. 130m by 90m) showing multiple car wrecks from the Tricolor (Lanckneus and Jonghe (2006)).

Feldens et al. (2009) presented the research of 2004 Indian Ocean Tsunami impacts on seafloor morphology and offshore sediments in the continental shelf next to Phang Nga province, especially around Pakarang Cape in Thailand, and provided some information about the seafloor. This research used a SSS to explore the image of the sea bottom, used a multi-beam echo sounder to investigate the depth of the sea (bathymetry) and used a grab sampler to take the sediment samples. It was found that the impact of the tsunami was most effective during the backwash flows as the sediment samples presented the stiff mud with grass, wood fragments and shells. Furthermore, various boulders were discovered in the channels in front of the Pakarang Cape (See Figures 9 - 11).

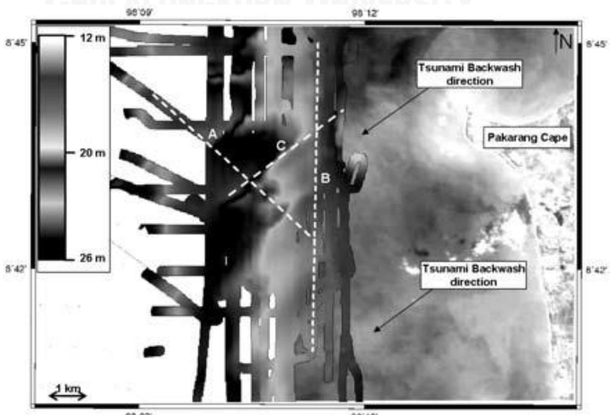


**Figure 9** Bathymetry around Pakarang Cape merged with a satellite image taken shortly after the 2004 tsunami (Feldens et al. (2009)).

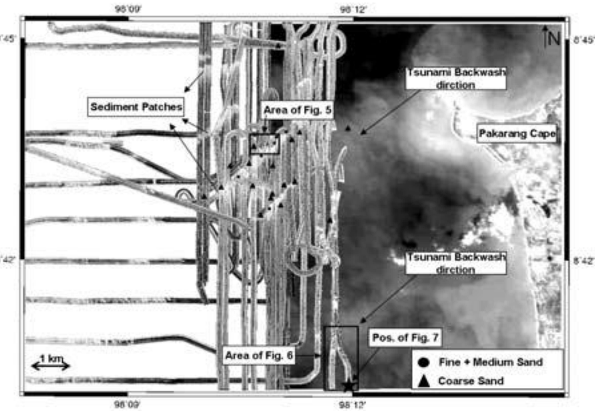


**Figure 10** Side Scan Sonar data merged with a satellite image taken shortly after the 2004 tsunami. Indicated are sediment types based on grain size analysis (Feldens et al. (2009)).

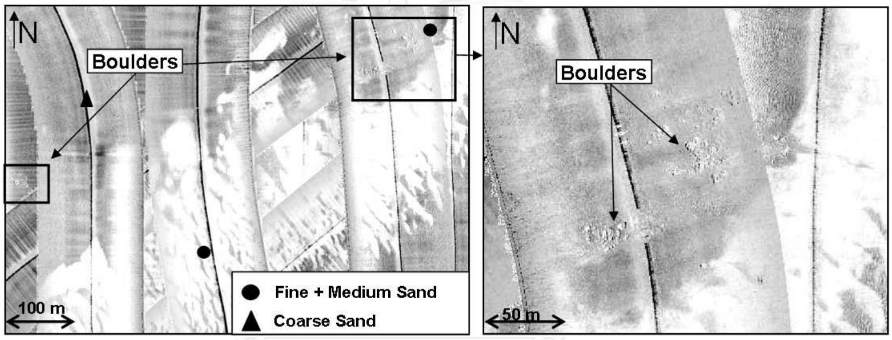


**Figure 11** Detailed view of one elongated sediment patch in front of Pakarang Cape (Feldens et al. (2009)).



Schwab et al. (2009) had done a survey and mapping to monitor and assess the coast and compare the change of the coast line from the past to present, including the influence of the movement of sediments along the northeastern coast of the U.S. state of South Carolina. The researchers were mapping the scope of geology (Geologic Framework), which included the three main parts: 1) a map showing the depth of water (bathymetry) 2) an image showing the morphology and the distribution of sediments on the seafloor (sonograph) 3) an image showing the structure and composition of the rocks and sediments beneath the sea floor (sub-bottom profile). The parts 1 and 2 were done by multi-beam echo sounder and SSS. Muti-beam echo sounder survey showed the depth of the sea and could be applied to provide the bathymetry map. The sonograph from SSS represented the morphology which included seafloor surface characteristics and distribution of the sediments on the seafloor. In addition, the researchers conducted sediment sampling in the area using a gravity core and analyzed the sediment samples to determine the particle size of the sediments.

Tauber (2009) studied the two dumping site in the Mecklenburg Bight in the south-western part of Baltic Sea. Two dumping test sites of dredged sediment (glacial till and mixed sediment with sand) in the south-western Baltic Sea were repeatedly investigated with SSS. The first survey was conducted before dumping, the second survey was conducted 1 week after dumping and eight more surveys were also run during the following three and a half years. The results showed that the heaps of dumped materials were eroded. Coarse materials remained at the surface and fine materials filled in the gaps between the heaps.

Savini (2011) applied the SSS to investigate sea floor conditions at the different sites located on the continental shelf of the Mediterranean Sea. Different ranges of the sonar were presented, illustrating the different resolution capacity of the employed high frequency (100 – 500 kHz) sonar systems. The sonographs were arranged in three paragraphs, according to their range, for a total of three sections (wide, medium, and small ranges). In each sonograph, where it was not specified, high levels of backscatter were shown as dark tones. Each section was introduced with an overview of the different types and spatial scale of seafloor features that could be investigated according to the employed range setting. The range setting was not an operational condition of the survey, because the tow fish must be located at a precise distance above the bottom, approximately between 10% and 20% of the range. As a result, the geomorphological setting and the survey environment did not always allow a free choice of the range setting. With the complex topography and a deep environment, it was not possible to use a narrow range that required the tow fish at a short distance from the bottom (this situation indeed did not guarantee the safety condition of towed equipment). In shallow water, we could not use a wide range because it was recommended to have more than 10% of the range setting as a distance above the bottom. Therefore, the range setting not only influenced the aim of the survey (because of the associated sonograph resolution), but also the depth range in which the survey could be performed. This research aimed to provide a useful reference document representing important seafloor features and sediment characteristics on continental shelf in the Mediterranean Sea. Summary of the three main classes of high frequency SSS range settings (from top to bottom: small, medium and wide range) is shown in Table 1.

| Range setting (m) | Optimum tow fish distance from the bottom | Resolution (m × pixel) | Geomorphological setting | Main aims of the survey |
|---|---|---|---|---|
| From few meters to 150 | 5 - 15 m | < 1 | Continental shelf in shallow water, between -10 and -30 m up to -50 m if the topographic features are known and without reliefs. | Research of specific target, such as small shipwrecks, Monitoring of underwater infrastructures, such as pipelines or other small structures. |
| 150 - 300 | 15 - 39 m | Ca. 1 | From 30 m of water depth down to the shelfbreak. | Meso-scale maps of the seafloor to represent a number of environment features (geological, sedimentological, geomorphological, habitat maps etc.). |
| 300 - 600 | 30 - 60 m | > 1 | From - 40 m up to the inner slope (600 m). | Meso-scale maps of the seafloor. |

**Table 1** Summary of the three main classes of high frequency SSS range settings (from top to bottom: small, medium and wide) with indication of the associated sonograph resolution, optimum geomorphological setting and aim of surveys (Savini (2011)).

Tang et al. (2011) analyzed the submarine geomorphic structure of the offshore sand mining area in Pearl River Estuary using SSS and investigated the bathymetry using single-beam echo sounder. Based on results, there were four types of geomorphology, shoal profile which showed several sets of clear and continuous strata reflecting interfaces, rough mining pit profile which showed a strong surface reflecting interfaces without other stratum displaying, smooth mining pit profile which showed weaker but clear and continuous surface reflecting interface with a blurred underlying reflection interface and semi-deep terrain which was similar to the smooth mining pit, but had a wide open area and a more curved seabed (See Figure 12).

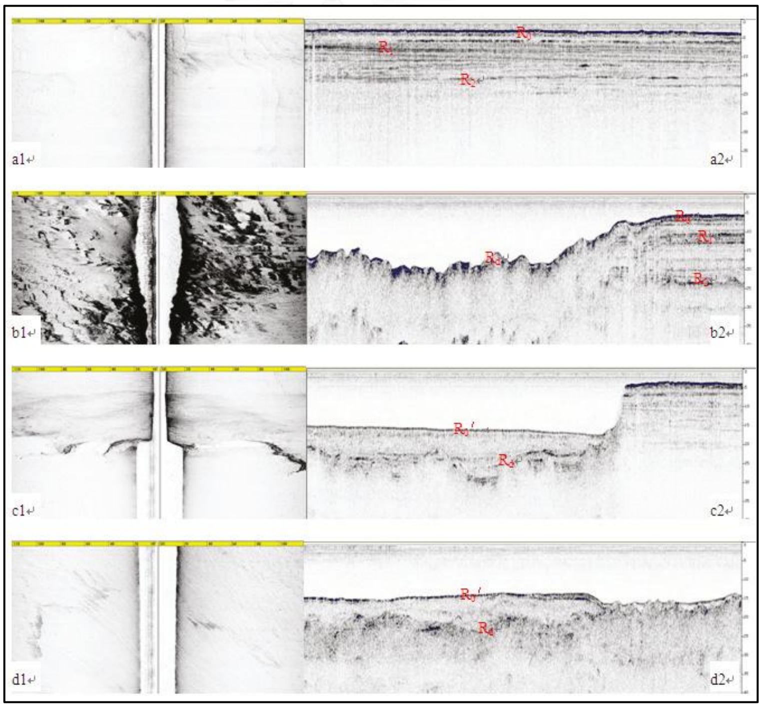


**Figure 12** There are four typical seabed geomorphologies and and their corresponding sub-bottom profiles in study site. (a) Remaining shoal shows smooth seabed, shallow water depth, and several sets of clear and continuous stratum reflecting interfaces. (b) Rough sand mining pit shows rough seabed, and strong surface reflecting interface, without other stratum displaying. (c) Smooth sand mining pit shows smooth seabed in the pit, and weaker but clear and continuous surface reflecting interface with a blurred underlying reflection interface. (d) Semi-deep terrain, similar to the smooth mining pit, but it has a wide open area and more curved seabed (Tang et al. (2011)).

Wilson and Bates (2012) applied the SSS and multi-beam echo sounder to investigate sea bottom conditions to detect the remain of sub-fossil woods in the An Eilein, a small lake in England. The sonograph showed that the traces of the sub-fossil wood were clear. The light grey elongate features (highlighted with ovals) shown in sonograph represented the sub-fossil wood materials (See Figure 13). The result from multi-beam echo sounder showed that the bathymetry of this study area was about 0 to - 22 m.

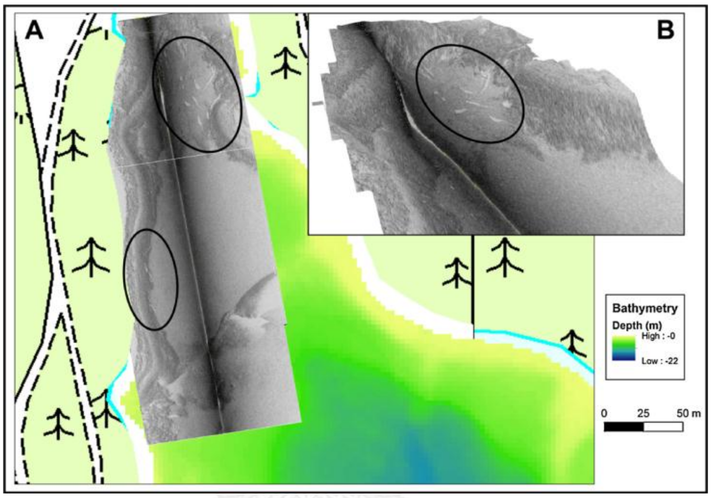


**Figure 13** (A) Bathymetric and side scan sonar results for the northern end of Loch an Eilein. (B) The upper right box shows a 3D view looking towards the northeast where the light grey elongate features (highlighted with ovals) represent the sub-fossil wood material (Wilson and Bates (2012)).

Haraguchi et al. (2013) analyzed the impact of the tsunami on the seafloor of the Kesennuma inner bay using 3D side-scan sonar to explore the damage and bathymetric change in the harbor. They presented the first direct evidence that the sea bottom sediments at the depth of 10 - 15 m were largely reworked by the 2011 Tohoku-oki Tsunami which caused the dune with the thickness of a few meters. Considering that the sea wave influence inside the inner bay was weak, meter-thick paleo-tsunami deposits were preserved in shallow sea bottoms with large bedforms (See Figure 14).

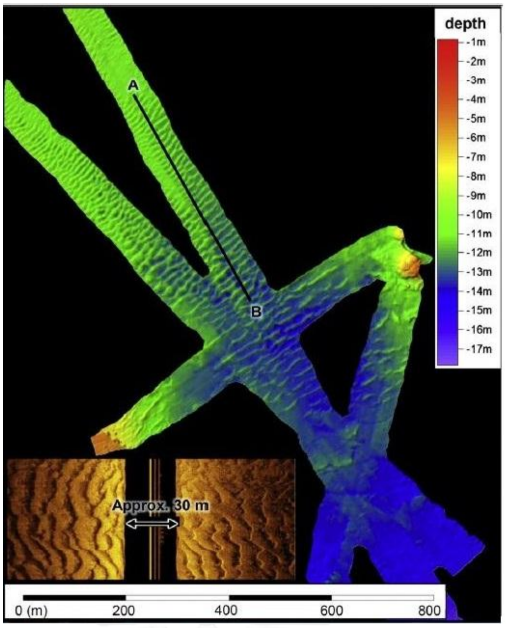


**Figure 14** Depth map around the large bedforms and side-scan image of the bedforms at the bottom of Kesennuma Bay is also shown (Haraguchi et al. (2013)).

## 2.5 Sediment Texture Classification

Sediment textures are classified by the fractions of each sediment separate (sand, silt, and clay) presents in sediment. Classifications are typically named for the primary constituent particle size or a combination of the most abundant particles sizes, e.g. "sandy clay" or "silty clay". A fourth term, loam, is used to describe a roughly equal concentration of sand, silt, and clay, and lends to the naming of even more classifications, e.g. "clay loam" or "silt loam" (Yard and Garden (2013)).

In the United States, twelve major sediment texture classifications are defined by the United States Department of Agriculture (U.S.D.A.). Determining the sediment textures is often aided with the use of a sediment texture triangle (Yard and Garden (2013)). This study use USDA system for determining sediment classification (see Table 2).

The sediment texture triangle gives names associated with various combinations of sand, silt and clay. A coarse-textured or sandy soil is one comprised primarily of medium to coarse size sand particles. A fine-textured or clayey soil is one dominated by tiny clay particles. Due to the strong physical properties of clay, a soil with only 20% clay particles behaves as sticky, gummy clayey soil. The term loam refers to a soil with a combination of sand, silt, and clay sized particles. For example, a soil with 30% clay, 50% sand, and 20% silt is called a sandy clay loam (Yard and Garden (2013)) (See Figure 15).

| **The Size of Sand, Silt and Clay** | |
|---|---|
| **Name** | **Particle Diameter (mm)** |
| Clay | below 0.002 |
| Silt | 0.002 to 0.05 |
| Very fine sand | 0.05 to 0.10 |
| Fine sand | 0.10 to 0.25 |
| Medium sand | 0.25 to 0.5 |
| Coarse sand | 0.5 to 1.0 |
| Very coarse sand | 1.0 to 2.0 |
| Gravel | 2.0 to 75.0 |
| Rock | greater than 75.0 (~2") |

**Table 2** Particle size classification in U.S.D.A. system (Yard and Garden (2013)).



All sediments consist of sand, silt, and clay with varying proportions. Based on these proportions, the sediments can be grouped into textural classes according to the component which is predominant (Bank (2011)) (See Table 3).

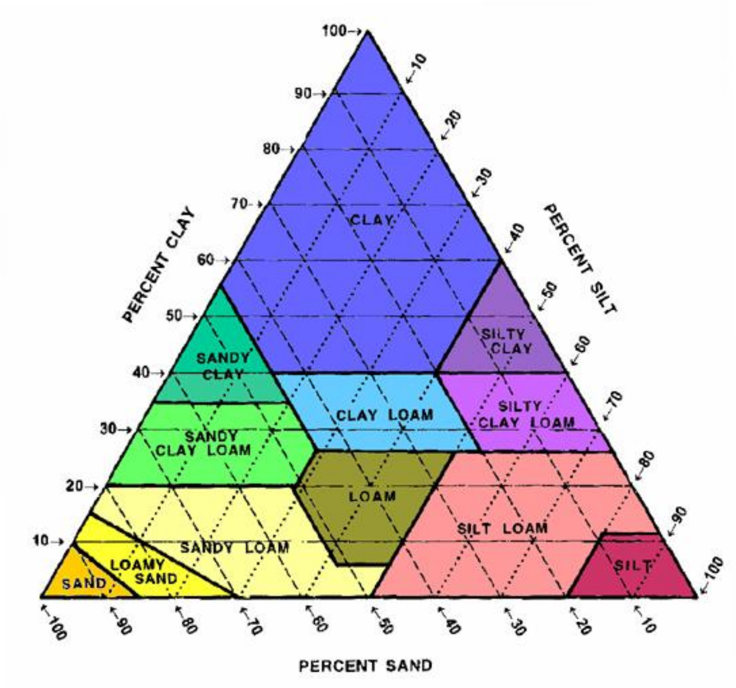


**Figure 15** Sediment Textural Triangle - Based on the triangle, a loamy soil has 40% sand, 20% clay and 40% silt. A sandy loam has 60% sand, 10% clay and 30% silt. [Source: U.S.D.A. (Yard and Garden (2013))]

| Class | Ranges (%) of | | |
|---|---|---|---|
| | Sand | Silt | Clay |
| Sand | 85 - 100 | 0 - 10 | 0 - 10 |
| Loamy sand | 70 - 90 | 0 - 30 | 0 - 15 |
| Sandy loam | 43 - 80 | 0 - 50 | 0 - 20 |
| Loam | 23 - 52 | 28 - 50 | 7 - 27 |
| Silt loam | 0 - 50 | 50 - 88 | 0 - 20 |
| Silt | 0 - 20 | 88 - 100 | 0 - 12 |
| Sandy clay loam | 45 - 80 | 0 - 28 | 20 - 55 |
| Clay loam | 20 - 45 | 15 - 53 | 27 - 40 |
| Silty clay loam | 0 - 20 | 40 - 73 | 27 - 40 |
| Sandy clay | 40 - 65 | 0 - 20 | 35 - 45 |
| Silty clay | 0 - 20 | 40 - 60 | 40 - 60 |
| Clay | 0 - 40 | 0 - 40 | 40 - 60 |

**Table 3** Sediment textural classes and range (%) of sand, silt and clay (Bank (2011)).

## 2.6 Water Content Determination

This test is performed to determine the water content of soils. The water content is the ratio, expressed as a percentage of the mass of “pore” or “free” water in a given mass of soil to the mass of the dry soil solids (Reddy (2015)). For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties (Reddy (2015)). The consistency of a fine-grained soil largely depends on its water content. The water content is also used in expressing the phase relationships of air, water, and solids in a given volume of soil. This study used Standard for China Clay for Ceramic Industry (Institute (1985)) to calculate the moisture in soil samples. The determination of the water content used the following equation:

$$\%\ \text{moisture} = \frac{m - m_1}{m} \times 100$$

in which:

$m$ = wet weight of the sample (g)

$m_1$ = weight of the sample after drying (g)

## 2.7 Cs-137 Concentration for Verifying Coastal Erosion

Caesium-137 (Cs-137) is one of radioisotopes of caesium with a nominal atomic mass of 137. It is an artificial radionuclide with a half-life of 30.3 years or so, which was released into the stratosphere by the testing of above ground thermonuclear weapons in the late 1950s and early 1960s and deposited as fallout (Exeter (2013)). Its high affinity to fine soil particles, relatively long half-life, and world-wide distribution of Cs-137 have made it almost a universal environmental tracer for studying upslope soil erosion and downstream sedimentation (Survey (2013)).

The basis of the Cs-137 technique can be summarized as follows (Exeter (2013)):

1) Cs-137 was primarily deposited as fallout during the late 1950s and the 1960s and rapidly and strongly absorbed by soil particles at the ground surfaces in most environments.

2) Subsequent redistribution of the radiocaesium reflects the movement of soil particles since the Cs-137 remains absorbed and moves in associated with the soil particles.

3) If it is assumed that the initial distribution of the Cs-137 fallout input was uniform, the deviations in the measured distribution of Cs-137 from the local fallout inventory represent the net impact of soil redistribution during the period since the deposition. Higher inventory indicates deposition and lower inventory indicates erosion.

4) If a relationship between Cs-137 loss or gain and soil loss or gain can be established, it will be possible to estimate rates of soil erosion or accretion from Cs-137 measurement.



Loughran et al. (1987) presented the study which use Cs-137 as a tracer to determine the status of soil erosion and sedimentation in the Jackmoor Brook catchment, Devon, U.K. It was postulated that 1) sites at the top of a cultivated slope should be most depleted of Cs-137, 2) sites at the base of a slope should contain greater amounts of Cs-137and have a distinctive depth profile, 3) hillslope erosion indicated by Cs-137 levels should be related to the length and angle of the slope, and 4) Cs-137 levels should discriminate between the chief source of sediment transferred to the stream (cultivated soils) and uncultivated soils (under pasture, orchards and woodland). These hypotheses were tested in two contrasting physiographic areas of the basin. Depletion of Cs-137 levels at the top of slopes indicated soil erosion, and deeper-than-plough-depth Cs-137 profiles at the base of slopes indicated sedimentation. These characteristics were most marked in the steeper, portion of the catchment, Upper Jackmoor. Slope-length effects on soil movement were more difficult to ascertain from the Cs-137 levels, but soil sampling of contrasting land-uses showed that cultivated soils had significantly less Cs-137, probably as a result of soil erosion. In general, the hypotheses were supported and the utility of the Cs-137 technique was confirmed.

Higgitt and Walling (1990) introduced the potential for using Cs-137 as an environmental tracer to indicate sources of soil erosion in the Chinese Loess Plateau. The Cs-137 contents of soil profiles were used to estimate soil erosion losses from different topographic and land use conditions at Lishi, Shanxi Province, and Luochuan, Shaanxi Province. At uncultivated sites Cs-137 has accumulated in the upper soil profile, whilst it has been mixed within the plough layer of cultivated soils. Eroded soils contain relatively less Cs-137, and simple calibration techniques are applied to quantify soil loss.

Saito et al. (2013) revealed the detail of the seafloor morphology at the middle of Ban Khun Samut Chin survey line. At A, C and B points in Figure 16(a), which are around 3, 5 and 8 km offshore, respectively, the core samples were taken to verify the erosion of the seafloor by Cs-137 concentration at depths of 0 to 4 cm. The results of Cs-137 concentration were shown in Figure 16(b). In core samples at A and C points, the activities in average are approximately 0.0008 and 0.0012 Bq/g, respectively. From the Figure 16(b), the core samples from A and C points contained levels of Cs-137 isotopes near or below the detection limit, while the Cs-137 concentration in the core sample at B point in average is approximately 0.0026 Bq/g which is much higher than the core samples at A and C points and also higher than the detection limit. Since, the high content of Cs-137 isotopes coincide with the deposition after the nuclear explosions, it is suggested A and C points or at around 3 and 5 km offshore are the areas where there have been erosions and B point or at around 8 km offshore is the area deposited by clay. Hence, sediments that eroded near the shore were taken by the waves in the sea and deposited on seafloor far away from the coast.

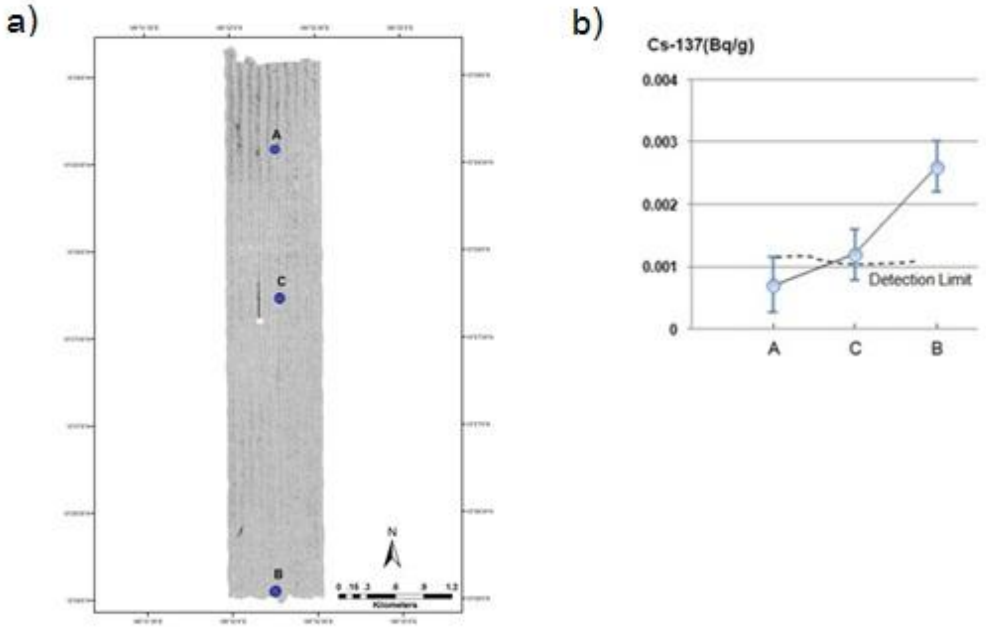


**Figure 16** a) Seafloor mosaic map by SSS survey at the middle of Ban Khun Samut Chin line; at A, C and B points show the points of sediment sampling (Saito et al. (2013; Suthisanonth et al. (2015)). b) Cs-137 concentrations in core samples at A, C and B sampling points (Saito et al. (2013; Suthisanonth et al. (2015)).

# CHAPTER III

# METHODOLOGY

The methodology is started from the literature reviews and data gathering in 3 main topics, bathymetry, seafloor morphology and sediment sampling. The bathymetry was studied by echo-sounding survey for the year 2012 and by the nautical maps from Hydrographic Department Royal Thai Navy (HDRTN) during the year 1960 – 2010, while the seafloor morphology was done by side-scan survey in the year 2012. Both echo-sounding survey and side-scan survey were done in all three lines as shown in Figure 1. In the part of detailed survey area, side-scan survey was also done to study the seafloor morphology. The elevation were taken to process into two ways. The first one is the derivation of digital elevation maps in the year 2012 to study the depth of the sea. The second one is the comparison of the bathymetric profiles during the year 1960 to 2012 to study the seafloor level change. The sonographs from side-scan survey were used to overlay with the DEMs derived from the elevation data in all three survey lines to study the relation between the seafloor morphology and bathymetry. For the part of sediment sampling, core sediments were collected at three survey lines by a gravity core and analyzed in three parts, grain-size distribution, water content, and Cs-137 concentration, to determine the relationship between the bathymetric profile and seafloor erosion in the study area. The chart of methodology is shown in Figure 17.

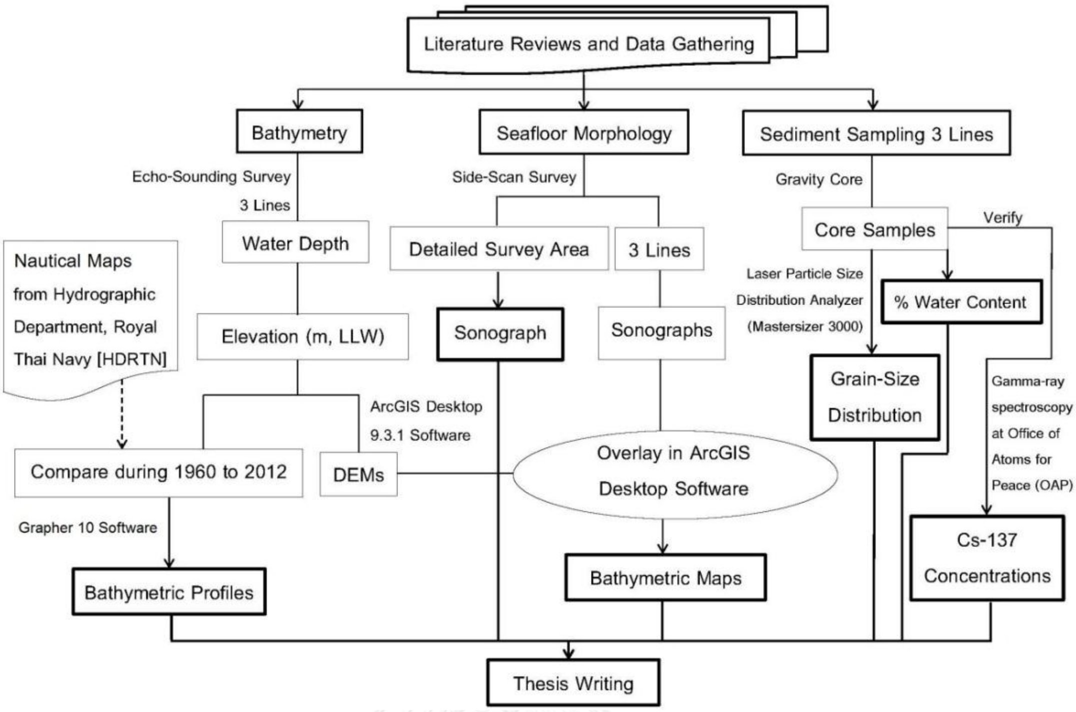


**Figure 17** The chart of methodology.

## 3.1 Bathymetry

All of the available bathymetric profiles were gathered to study the change of the seafloor. The bathymetric profile in the year 1960 was derived from the contour lines in the nautical map (Hydrographic Department, Royal Thai Navy [HDRTN]) cited in Jarupongsakul (2010), the bathymetric profiles in the years 1972, 1980, 1984, 1988, 1999, 2004 and 2008 were derived from the contour lines in the nautical maps [HDRTN], and the bathymetric profile in the year 2010 was derived from the echo-sounding method survey cited in Jarupongsakul (2010). Moreover, Geological Survey of Japan (AIST) has conducted the echo-sounding survey in the year 2012. The survey was conducted in three lines as shown in Fig. 1. ODOM Hydrotrac™ single-beam echo sounder with a working frequency of 200 kHz was welded to the portside of the boat to record the depth of the sea at every second. The water depth was used to calculate the elevation and generate the Digital Elevation Model (DEM). In addition, the elevation was applied to plot the bathymetric profile in 2012 and compare to the others previous year. The nautical maps derived from HDRTN were shown in Appendix B.

Throughout this research, times are given in local standard time (UTC+7) and positions are indicated in the local coordinate system (WGS84 geographic coordinate system). The mean sea level in the year 2012 is assumed to be 2.46 m above the chart datum near the Chao Phraya Delta station.

### 3.2 Seafloor Morphology

The seafloor morphology was studied by SSS. This tool has been widely used to map the seafloor in many sea exploration programs (Bates and Moore (2002; Savini (2011; Survey (2013; Tauber (2009)). The SSS surveyed was conducted in three lines from the shore to 12 km offshore in both outgoing and returning boat as shown in Figure 1. In addition, the survey was conducted over the area of 2 × 5 $km^2$ in the middle part of the Ban Khun Samut Chin line in detail. The total number of lines in that area was 20 and the gap between each line was 100 m as shown in Figure 18. The survey was conducted with the Imagenex Model 872 "YellowFin" SSS for both three lines and the area of 2 × 5 $km^2$ in the middle part of the Ban Khun Samut Chin line. The working frequency was 330 kHz and maximum operating depth was 300 m. The transducer was tilted down for 20° beside the boat and swaths over the seafloor with a width of 50 m along each side of the nadir line. The boat was moving with a velocity of 7 - 8 miles per hour and the sonographs were recorded along the way. The coordinates were recorded by GPS. The obtained sonographs from the 3 survey lines were used to overlay with the DEMs and generate the bathymetric maps.

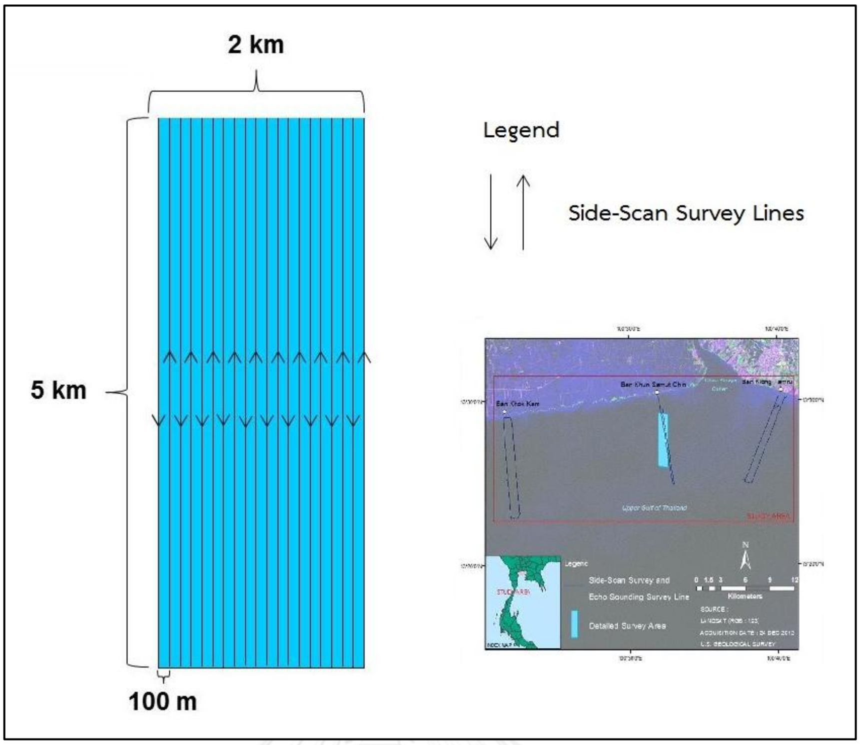


**Figure 18** Side-scan survey at detailed survey area.

### 3.3 Sediment Sampling

The sediment samplings were conducted at Ban Khun Samut Chin, Ban Klong Tamru and Ban Khok Kam survey lines by a gravity core and the coordinates were recorded by GPS. The sampling points of the 3 survey lines were shown in Figures 19 - 22.

At Ban Khun Samut Chin line, seven sediment cores at 1, 2, 3, 4, 6, 8 and 10 km offshore were obtained. These cores had the depth of 15, 20, 20, 20, 30, 30 and 35 cm, respectively. For Ban Klong Tamru line, four sediment cores were obtained at 4, 6, 8 and 10 km offshore. These cores had the depth of 5, 5, 3 and 7 cm, respectively. For Ban Khok Kam line, five sediment cores were obtained at 2, 4, 6, 8 and 10 km offshore. These cores had the depth of 16, 15, 5, 15 and 10 cm, respectively.

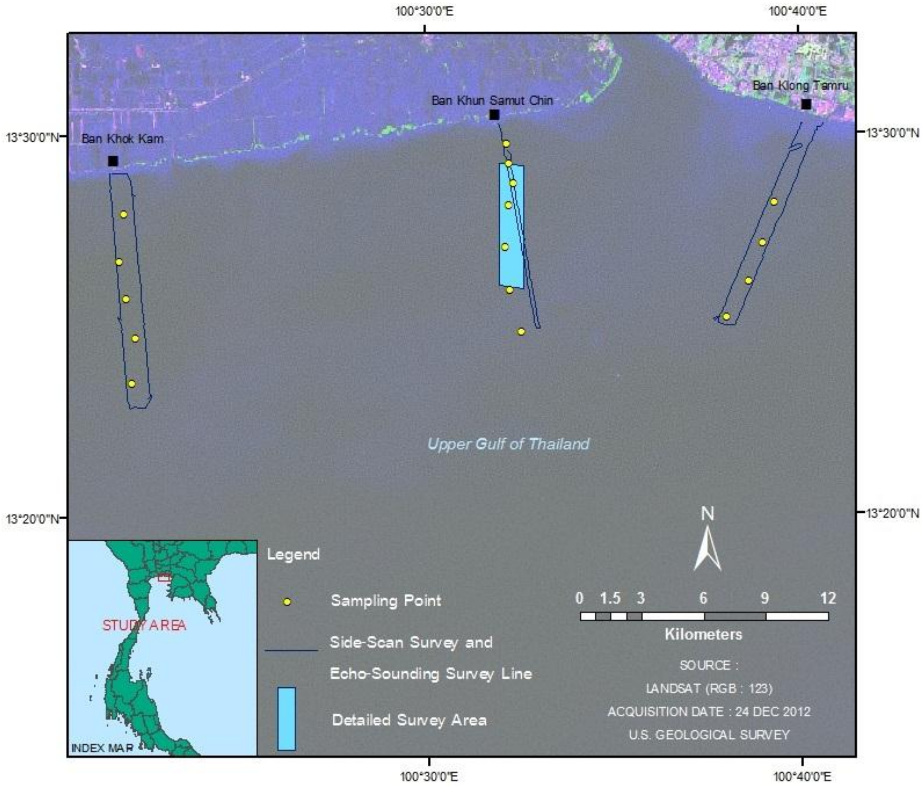


**Figure 19** Sampling points of three survey lines.

The core was separated at every 5 cm depth for each core samples. The exception is at Ban Klong Tamru and Ban Khok Kam survey lines where the separation was done by the different physical feature that can be seen in some cores. All separated sediment cores were taken to determine the water content (Institute (1985)) and the particle-size distribution. Moreover, the upper layer of each core was also taken to verify the Cs-137 concentration (Exeter (2013)) (see Table 4).

| Survey Line | Distance (km) Offshore | Point | Core Depth (cm) | Sample No. for Water Content | Sample No. for Particle-Size Distribution | Sample No. for Cs-137 Concentration |
|---|---|---|---|---|---|---|
| Ban Khun Samut Chin | 1 | A | 0 - 5 | W1 | P1 | Cs1 |
| | | | 5 - 10 | W2 | P2 | Cs2 |
| | | | 10 - 15 | W3 | P3 | - |
| | 2 | B | 0 - 5 | W4 | P4 | Cs3 |
| | | | 5 - 10 | W5 | P5 | Cs4 |
| | | | 10 - 15 | W6 | P6 | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 15 - 20 | W7 | P7 | - |
| | 3 | C | 0 - 5 | W8 | P8 | Cs5 |
| | | | 5 - 10 | W9 | P9 | Cs6 |
| | | | 10 - 15 | W10 | P10 | - |
| | | | 15 - 20 | W11 | P11 | - |
| | 4 | D | 0 - 5 | W12 | P12 | Cs7 |
| | | | 5 - 10 | W13 | P13 | Cs8 |
| | | | 10 - 15 | W14 | P14 | - |
| | | | 15 - 20 | W15 | P15 | - |
| | 6 | E | 0 - 5 | W16 | P16 | Cs9 |
| | | | 5 - 10 | W17 | P17 | Cs10 |
| | | | 10 - 15 | W18 | P18 | - |
| | | | 15 - 20 | W19 | P19 | - |
| | | | 20 - 25 | W20 | P20 | - |
| | | | 25 - 30 | W21 | P21 | - |
| | 8 | F | 0 - 5 | W22 | P22 | Cs11 |
| | | | 5 - 10 | W23 | P23 | Cs12 |
| | | | 10 - 15 | W24 | P24 | - |
| | | | 15 - 20 | W25 | P25 | - |
| | | | 20 - 25 | W26 | P26 | - |
| | | | 25 - 30 | W27 | P27 | - |
| | 10 | G | 0 - 5 | W28 | P28 | Cs13 |
| | | | 5 - 10 | W29 | P29 | Cs14 |
| | | | 10 - 15 | W30 | P30 | - |
| | | | 15 - 20 | W31 | P31 | - |
| | | | 20 - 25 | W32 | P32 | - |
| | | | 25 - 30 | W33 | P33 | - |
| | | | 30 - 35 | W34 | P34 | - |
| Ban Klong Tamru | 4 | A | 0 - 5 | W35 | P35 | Cs15 |
| | 6 | B | 0 - 5 | W36 | P36 | Cs16 |
| | 8 | C | 0 - 3 | W37 | P37 | Cs17 |
| | 10 | D | 0 - 2.5 | W38 | P38 | Cs18 |
| | | | 2.5 - 5 | W39 | P39 | Cs19 |
| | | | 5 - 7 | W40 | P40 | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ban Khok Kam | 2 | A | 0 - 2 | W41 | P41 | Cs20 |
| | | | 2 - 6 | W42 | P42 | Cs21 |
| | | | 6 - 11 | W43 | P43 | - |
| | | | 11 - 16 | W44 | P44 | - |
| | 4 | B | 0 - 5 | W45 | P45 | Cs22 |
| | | | 5 - 10 | W46 | P46 | Cs23 |
| | | | 10 - 15 | W47 | P47 | - |
| | 6 | C | 0 - 5 | W48 | P48 | Cs24 |
| | 8 | D | 0 - 5 | W49 | P49 | Cs25 |
| | | | 5 - 10 | W50 | P50 | Cs26 |
| | | | 10 - 15 | W51 | P51 | - |
| | 10 | E | 0 - 5 | W52 | P52 | Cs27 |
| | | | 5 - 10 | W53 | P53 | Cs28 |

**Table 4** Core samples at each sampling points which were taken to determine % water content, particle-size distribution, and Cs-137 concentration.

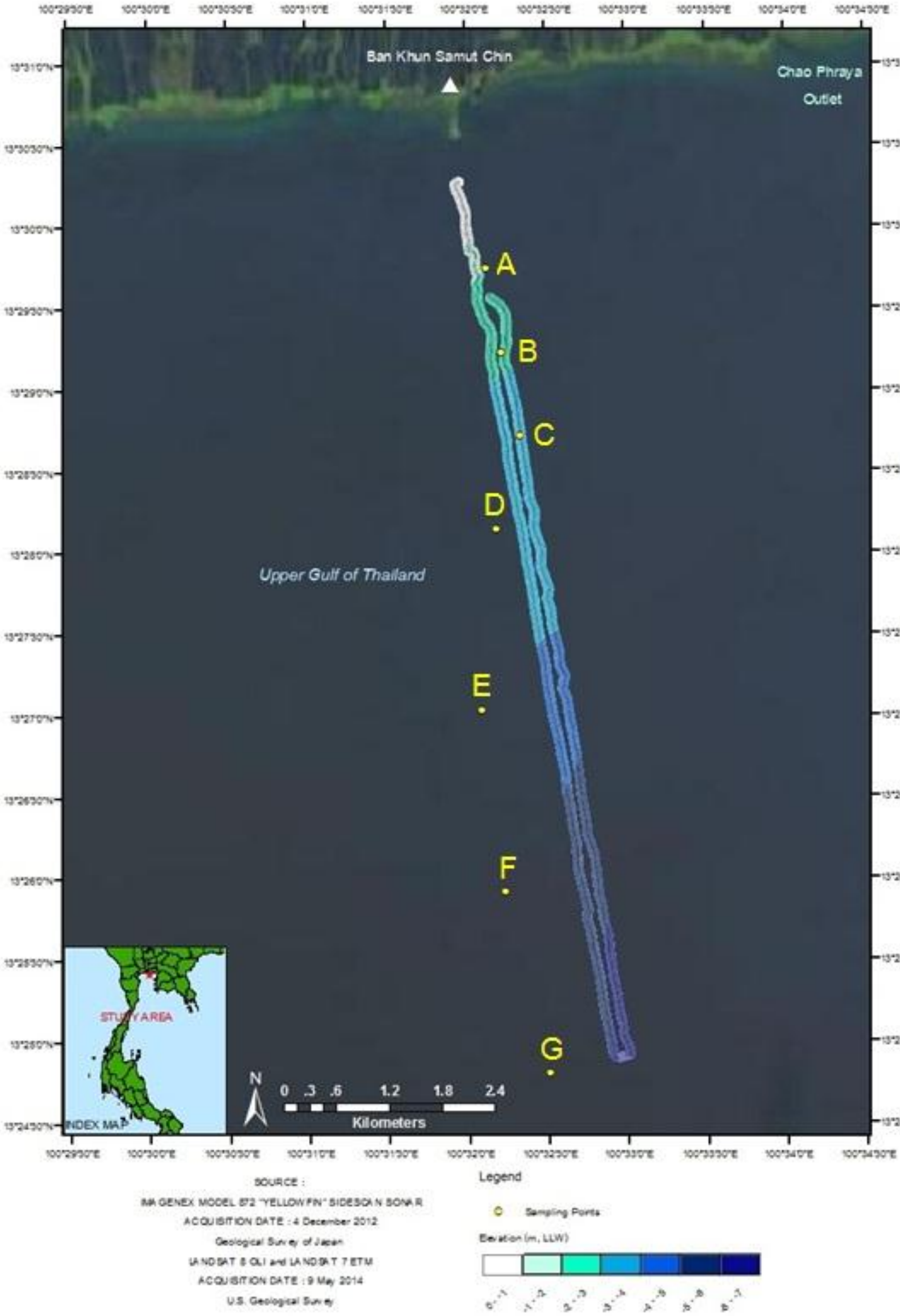


**Figure 20** Sediment sampling points at Ban Khun Samut Chin survey line. Sonograph data is derived from Geological Survey of Japan (2012).

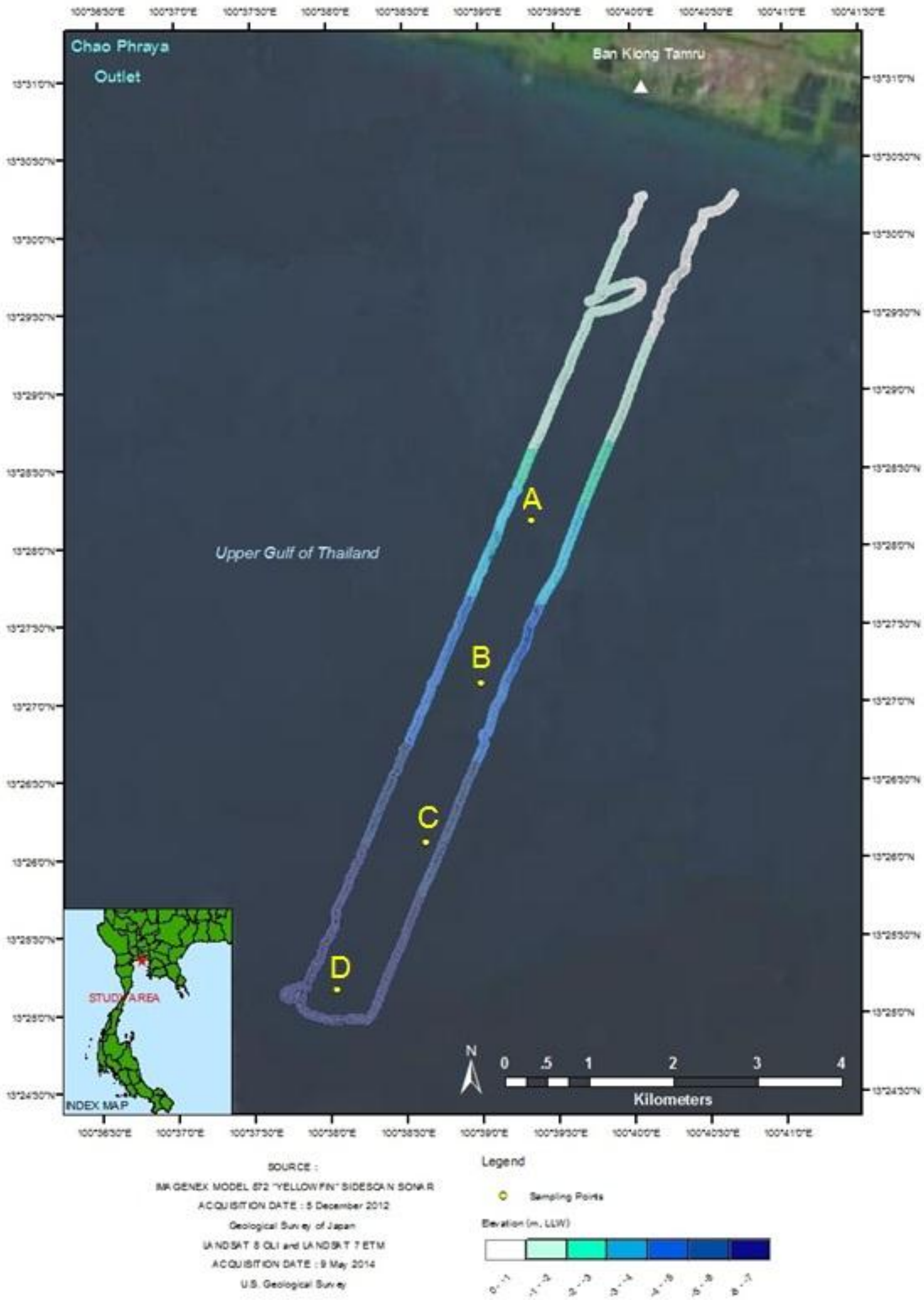


**Figure 21** Sediment sampling points at Ban Klong Tamru survey line. Sonograph data is derived from Geological Survey of Japan (2012).

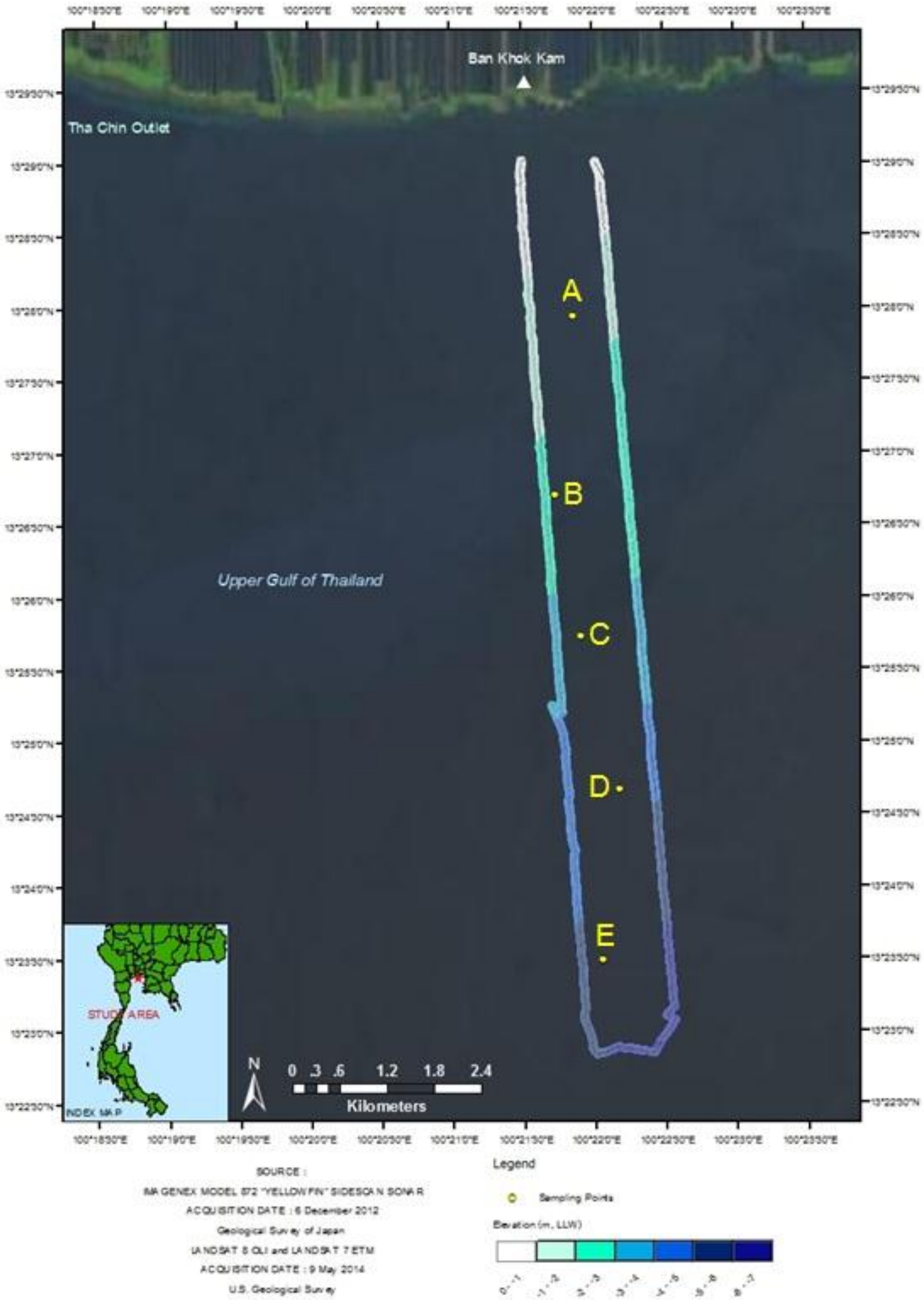


**Figure 22** Sediment sampling points at Ban Khok Kam survey line. Sonograph data is derived from Geological Survey of Japan (2012).

### 3.3.1 Water Content

All samples were taken to determine the water content at Metallurgy and Materials Science Research Institute, Chulalongkorn University. The water content can be calculated by Standard for China Clay for Ceramic Industry (Institute (1985)). Test procedures are as the followings;

1. Determination of the mass of wet soil sample
2. Drying the sample in the oven at the temperature of 105 °C until the sample is dry.
3. Determination of the mass of the dry sample
4. Calculation of the water content

### 3.3.2 Particle-Size Distribution

In order to determine the particle-size distribution, the sediment samples were dried and sieved at 1 mm sieve-diameter. The amount of 2 g/sample was used in laser particle size analyzer at Scientific and Technological Research Equipment Centre, Chulalongkorn University. The instrument type is Malvern, Mastersizer 3000. The instrument serial number is MAL1099267 and the accessory name is Hydro EV. The particle-size is reported as the percent volume of density for each the size class (μm). The percent of 3 components (clay, silt, sand) are taken to classify the textural type in sediment textural triangle (U.S.D.A.) (Yard and Garden (2013)). In addition, the percent of 3 components were also taken to determine the relationship between percent volume of density and the core depth (cm) in each core samples.

### 3.3.3 Cs-137 Concentration

In order to verify the Cs-137 concentration, the sediment samples were dried and sieved at 1 mm sieve-diameter. The amount of 7 g/sample was measured by 662-keV gamma-ray spectroscopy at the Office of Atoms for Peace (OAP). Then, the results are taken to plot the graphs which represent the relationship between the values of Cs-137 concentration (Bq/g) and the distance (km) offshore. Finally, the points of erosion and deposition are estimated for each location.

# CHAPTER IV

# RESULTS AND INTERPRETATION

## 4.1 Bathymetric Profiles of Three Survey Lines

Figure 23 shows bathymetric profiles of the 3 survey lines during the year 1960 -2012. The lowest low water level (LLW) and the mean sea level (MSL) were as of the year 2012 in which the LLW was defined as 2.46 below the MSL. The bathymetric profiles at Ban Khok Kam which were compared among the years 1960, 1980, 1988, 2004, 2008, 2010 and 2012 show that the coasts when the tide was lowest were about 1.6, 1.1, 0.9, 0.5, 0.4, 0.4 and 0.4 km width, respectively. From 1960 to 2012 (52 years), the seafloor at Ban Khok Kam survey line was eroded for about 2 m. In 1960, the muddy coast when tide was lowest was about 1.6 km width, while it was only about 0.4 km width in 2012. This finding indicates that the muddy coast was shortened for about 1.2 km within 52 years. The bathymetric profiles at Ban Khun Samut Chin which were compared among the years 1960, 1972, 1984, 1988, 1999, 2008, 2010 and 2012 show that the coasts when the tide was lowest were about 2.6, 2.3, 1.9, 1.9, 1.4, 1, 1 and 1 km width, respectively. The seafloor at Ban Khun Samut Chin survey line was eroded for about 3 m within 52 years. In 1960, the muddy coast when the tide was lowest was about 2.6 km width, while it was only about 1 km width in 2012. This finding indicates that the muddy coast was shortened for about 1.6 km within 52 years. The bathymetric profiles at Ban Klong Tamru which were compared among the years 1960, 1972, 1984, 1988, 1999, 2008, 2010 and 2012 show that the coasts when the tide was lowest were about 5, 4, 2.5, 2.5, 1.7, 1, 1 and 1 km width, respectively. The seafloor at Ban Klong Tamru survey line was eroded for about 2 m. In 1960, the muddy coast when the tide was lowest was about 5 km width while it was only about 1 km width in 2012. This finding indicates that the muddy coast was shortened for about 4 km within 52 years. All bathymetric profiles comparisons in these 3 lines suggest that the coast was being gradually shortened since these profiles reveal the change of the coast in the long period. However, the change can hardly be seen the short period. Hence, it can be concluded that, there has been the erosion in the study area, but it is hard to observe in the short time scale.

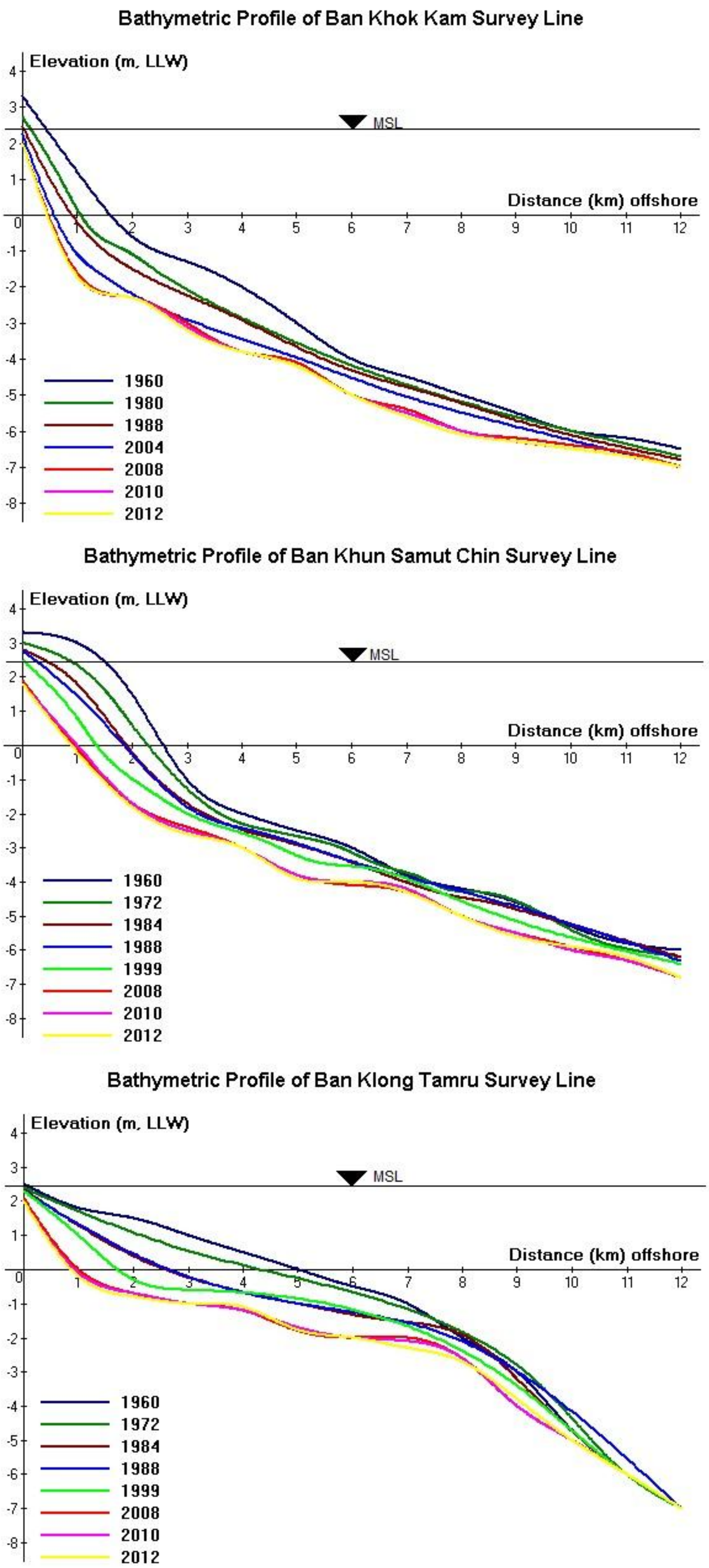


**Figure 23** Bathymetric profiles from shorelines to 12 km offshore during 1960 to 2012 at three survey lines (Suthisanonth et al. (2015)).

## 4.2 Sonographs of Three Survey Lines and Detailed Survey Area

Figures 24, 25, and 26 represent the sonographs of Ban Khun Samut Chin, Ban Klong Tamru, and Ban Khok Kam survey lines, respectively. The sonographs reveal the elongated sediment patches which appear in nearly white color. Light-colored areas in the sonograph correspond to finer or non-consolidated sediment, while darker areas correspond to coarser or more consolidated sediment (Feldens (2009)). In this study, the sonographs show light-color surface. This result suggests that the sediments on the seafloor consist of soft materials. The collected samples also support the result since most of them consist of clay and silt mixed up with a little sand (see the detail in the section 4.4.2).

The result of detailed survey area represented as the sonograph which shows the obvious seafloor morphology of the middle of Ban Khun Samut Chin survey line. Both sonograph and collected samples from all 3 survey lines reveal that the sediments on the seafloor are soft materials. In some part around 2 - 4 km offshore, the sonograph reveals the darker areas which are presented of the scratched features on the seafloor. These scratches are caused by mussel farming. During the survey, it is found that this area was full of the bamboo sticks in the sea which is from mussel farming. In addition, sometimes, these features can be found at the further offshore. They are caused by offshore fisheries (See Figure 27).


**Figure 24** Sonograph of Ban Khun Samut Chin survey line. Sonograph data is derived from Geological Survey of Japan (2012).


**Figure 25** Sonograph of Ban Klong Tamru survey line. Sonograph data is derived from Geological Survey of Japan (2012).


**Figure 26** Sonograph of Ban Khok Kam survey line. Sonograph data is derived from Geological Survey of Japan (2012).

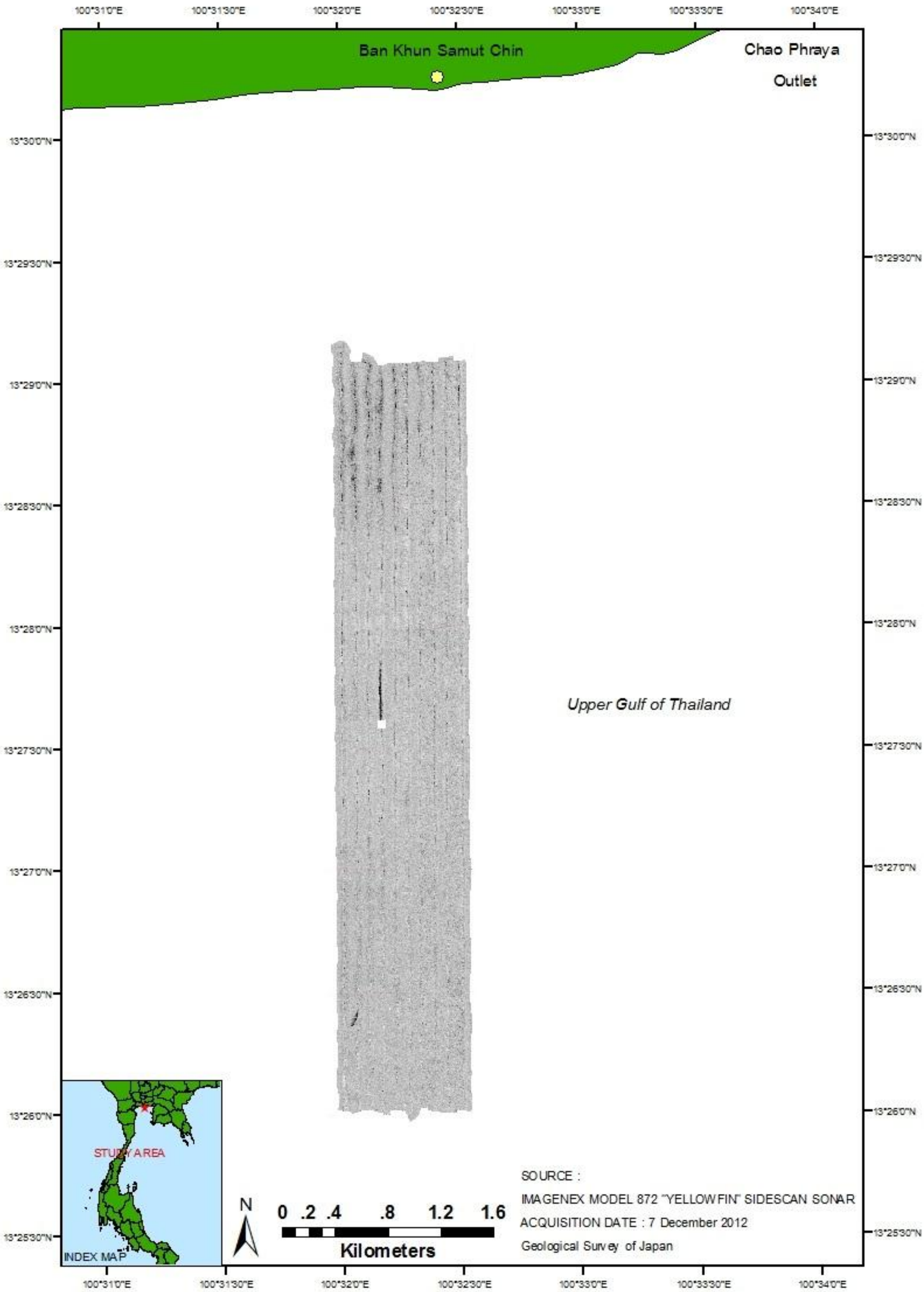


**Figure 27** Seafloor mosaic map by SSS survey at the middle of Ban Khun Samut Chin survey line. Sonograph data is derived from Geological Survey of Japan (2012) (Saito et al. (2013)).

## 4.3 Bathymetric Maps of Three Survey Lines

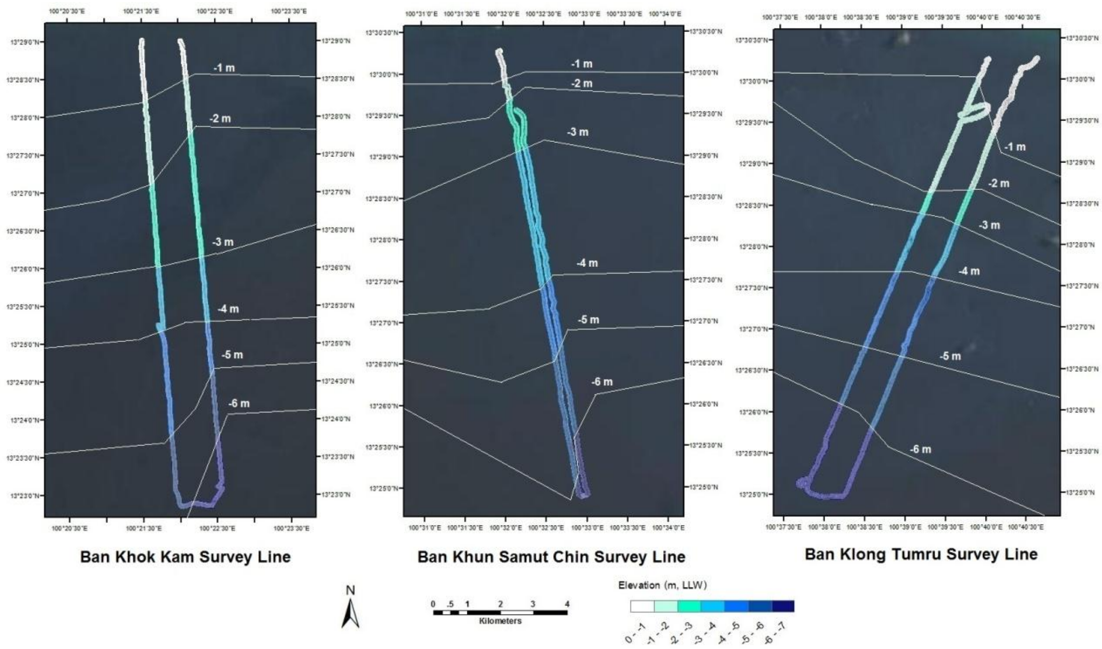


**Figure 28** Bathymetric maps of three survey lines (Suthisanonth et al. (2015)). Sonographs data are derived from Geological Survey of Japan (2012).

Figure 28 shows the layout of the seafloor and the elevation of three surveying routes. From the results of single-beam echo sounding surveys of three survey lines, the elevation from the coast to 12 km offshore is between 0 to -7 m (LLW). The elevations of -1, -2, -3, -4, -5 and -6 m (LLW) were 2, 4, 6, 8, 10 and 12 km offshore, respectively, at Ban Khok Kam survey line. At Ban Khun Samut Chin survey line, the elevations of -1, -2, -3, -4, -5 and -6 m (LLW) were 1, 2, 3, 7, 9 and 12 km offshore, respectively, and at Ban Klong Tamru survey line, they were 1, 4, 5, 7, 9 and 11 km offshore, respectively. The bathymetric maps of three survey lines are shown in Appendix B.

## 4.4 Sediment Analysis

4.4.1 Water Content

Figures 29, 30, and 31 illustrate percents of water content in sediment core samples at Ban Khun Samut Chin, Ban Klong Tamru, and Ban Khok Kam survey lines, respectively.

At Ban Khun Samut Chin survey line (see Figure 29), the water content is lower in the deeper strata layers of the sediment but higher in the farther offshore area. Most samples have more than 50 percent water content. This result suggests that the density of the sediment is lower than 50 percent. At 1 – 6 km offshore, the water contents are less. The result suggests that the sediments in these areas are stiff muds or primitive sediments due to the fact that these sediments have high density (high compactness in sediment particle) which cause the percent of water being low (Saito et al. (2013)). In addition, from the reports of land subsidence situation since 1978 (Teartisup and Kerdsueb (2013)) show that the pumping out of groundwater from the main aquifer layers caused the drawn down. There are two main centers of depression, one is in the eastern Bangkok, extending in a north-south direction at about 15 – 20 km east of the Chao Phraya River. Another one is located at the west and north of Samut Sakhon province. The findings of these reports support the result that the water content is lower in the deeper layers, especially, in the nearshore areas around 1 – 2 km offshore where it is suspected to be highly affected by land subsidence from overpumping of groundwater (Bhattacharya (2013)). However, the water content is higher in the farther offshore areas, from 8 km offshore. The result suggests that the sediments in these areas are soft muds or non-primitive sediments since these sediments have low density (low compactness in sediment particle) (Saito et al. (2013)).

At Ban Klong Tamru survey line (see Figure 30), the water content cannot be clearly determined because the collected sediments are of low volume. However, the result also shows that the water content is lower in the deeper strata layers of the sediment and higher in the farther offshore area. The higher water content is obvious at 10 km offshore. All samples have less than 50 percent water content. It is because that at Ban Klong Tamru survey line, most of the core sediments are composed of sand (see the details in the section 4.4.2) which has low efficiency to absorb the water and do not exhibit properties of swelling, shrinkages, stickiness and plasticity. Sand particles are large and have little exposed surface area (0.1 $m^2/g$ specific area) (Bank (2011)).

At Ban Khok Kam survey line (see Figure 31), the result shows that the water content is lower in the deep strata layers of the sediment but higher in the farther offshore area as well. At the distance of 2 - 8 km offshore, all samples have low percent of water content. The result suggests that the sediments in these areas are stiff muds (Saito et al. (2013)). However, at 10 km offshore, the water content is high and it is suggested that the sediments in these areas are soft muds (Saito et al. (2013)).

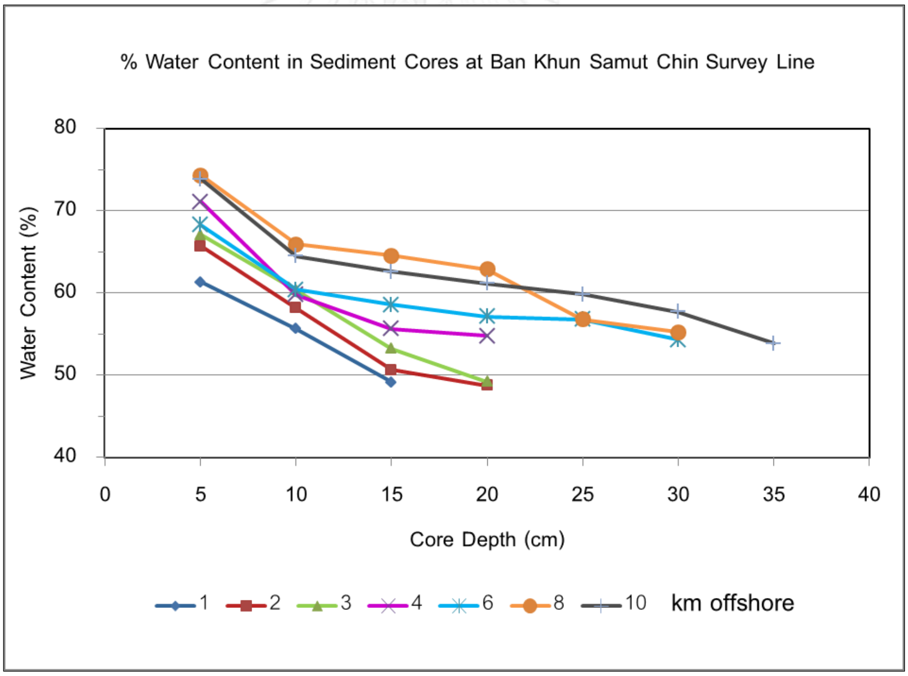


**Figure 29** Water content in sediment cores at Ban Khun Samut Chin survey line.

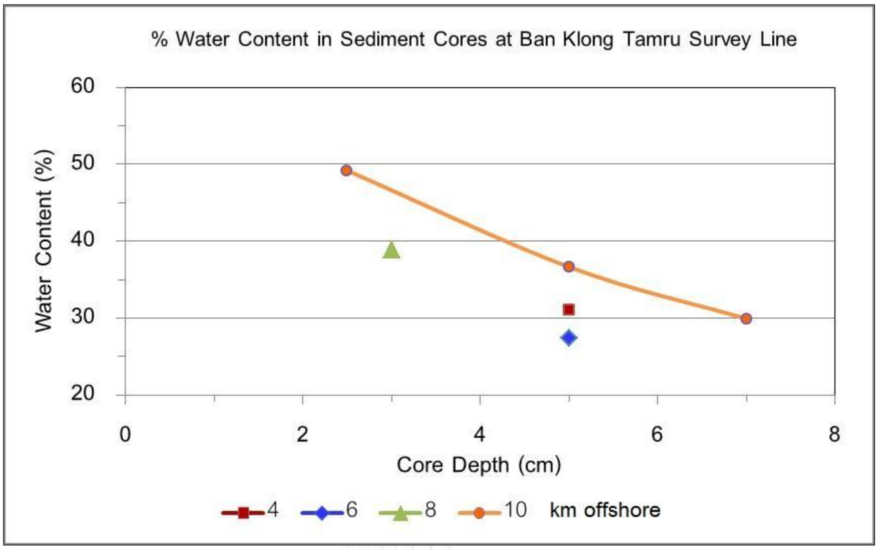


**Figure 30** Water content in sediment cores at Ban Klong Tamru survey line.

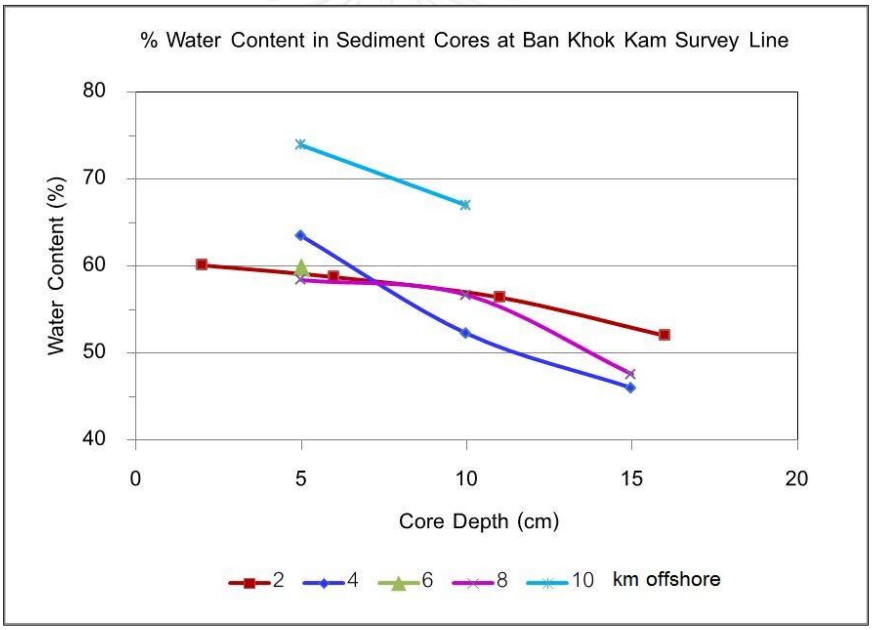


**Figure 31** Water content in sediment cores at Ban Khok Kam survey line.

4.4.2 Particle-Size Distribution

The result from laser particle-size distribution analysis represents the size of sample in micron unit (µm) and percent volume in sample. This study used U.S.D.A. system (Yard and Garden (2013)) for determining sediment classification and separating to percent of clay (< 2 µm), silt (2 – 50 µm) and sand (50 – 100 µm). Then, for each sample, the percent of these components are used to plot into sediment textural triangle (U.S.D.A.) (Yard and Garden (2013)).

For Ban Khun Samut Chin survey line, the result shows that all of 34 sediment samples are silt loam (see Appendix D). The particle-size distribution in core samples at Ban Khun Samut Chin survey line is shown in Figure 32. The layer at 0 – 5 cm depth in core sample at 1 km offshore and the layer at 5 – 10 cm depth in core sample at 2 km offshore are correlated to each other since the components are similar with 9 – 14 % of sand. The layer at 5 – 15 cm depth in core sample at 1 km offshore, the layer at 0 – 5, and 10 – 20 cm depth in core sample at 2 km offshore and all of layer in core sample at 4 km are correlated to one another since the components are similar with 3 – 5 % of sand. In addition, all layers in core samples at 3, 6, 8 and 10 km offshore since the components are similar with 0 – 2 % of sand. Therefore, it is suspected that at 1 km offshore in the first layer (0 – 5 cm depth) in core sample and at 2 km offshore in the second layer (5 – 10 cm depth) in core sample, high percent of sand was found. It is due to the fact that the area is near the Chao Phraya River mouth where there are tidal mud flats with the bedload sediments brought down from the river (Uehara et al. (2010)). Cohesive sediments, such as clay and small-particle mud are easily suspended by water currents (Wang and Andutta (2013)). Alternatively, non-cohesive sediments such as sand are usually transported along the bottom by the processes of saltation, rolling, and sliding (Wang and Andutta (2013)). As a result, sand was deposited near the coast, while clay or small-particle mud was suspended along water current and deposited farther offshore.

For Ban Klong Tamru survey line, the result of all 6 sediment samples are shown as follows; at 4 km offshore in core sample layer at 0 – 5 cm depth the sediment is sandy loam, at 6 km offshore in core sample layer at 0 – 5 cm depth the sediment is loamy sand, at 8 km offshore in core sample layer at 0 – 3 cm depth the sediment is loam, as well as at 10 km offshore in core sample layer at 0 – 2.5 cm depth, and at 10 km offshore in core sample layer at 2.5 – 7 cm depth, the sediment is silt loam (see Appendix D). The data of particle-size in this line reveals that the sediment textures of the seafloor are rather rough. However, the collected core samples in this survey line are few because the most of sediments on the seafloor are mixed up with sand which is difficult to pick by the gravity core. The particle-size distribution in core samples at Ban Klong Tamru survey line is shown in Figure 33. Most of the sediments on seafloor are collected only in the upper layer that is mostly consisted of sand except in the far offshore area, 8 - 10 km offshore where sediments are loam or silt loam. The core samples in this line contain higher percent of sand because of the geomorphology of the area which is the sedimental transport channel route of Chao Phraya River mouth (GISTDA (2012)).

At Ban Khok Kam survey line, most of the samples are silt loam, except at 10 - 15 cm depth of 4 km offshore and 10 – 15 cm depth of 8 km offshore where sediments are silty clay loam (see Appendix D). The particle-size distribution in core samples at Ban Khok Kam survey line is shown in Figure 34. The results show that most of the sediments are silt loam in all layers. At the deeper layer, 10 - 15 cm depth, sediments are finer and can be classified as silty clay loam.

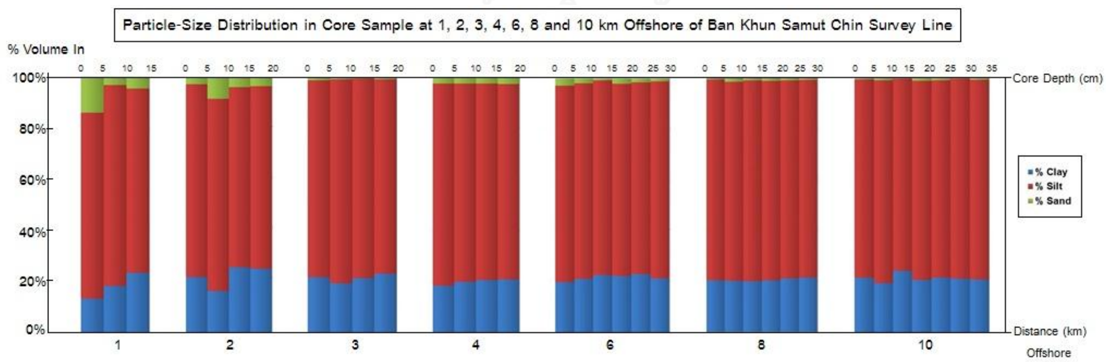


**Figure 32** Particle-size distributions in core samples at 1, 2, 3, 4, 6, 8, and 10 km offshore of Ban Khun Samut Chin survey line.

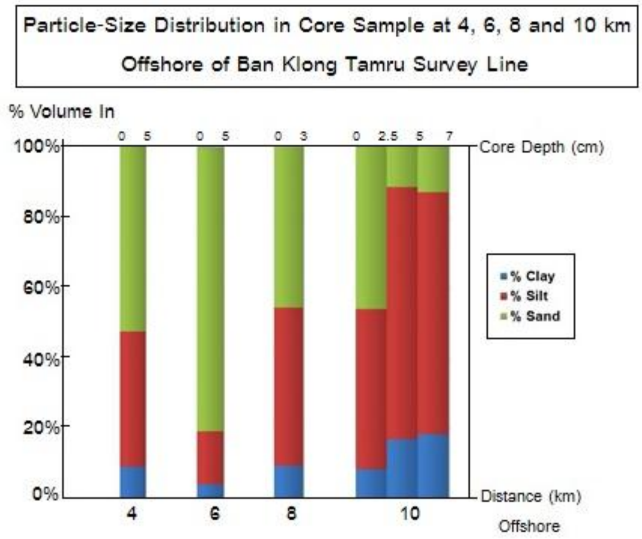


**Figure 33** Particle-size distributions in core samples at 4, 6, 8, and 10 km offshore of Ban Klong Tamru survey line.

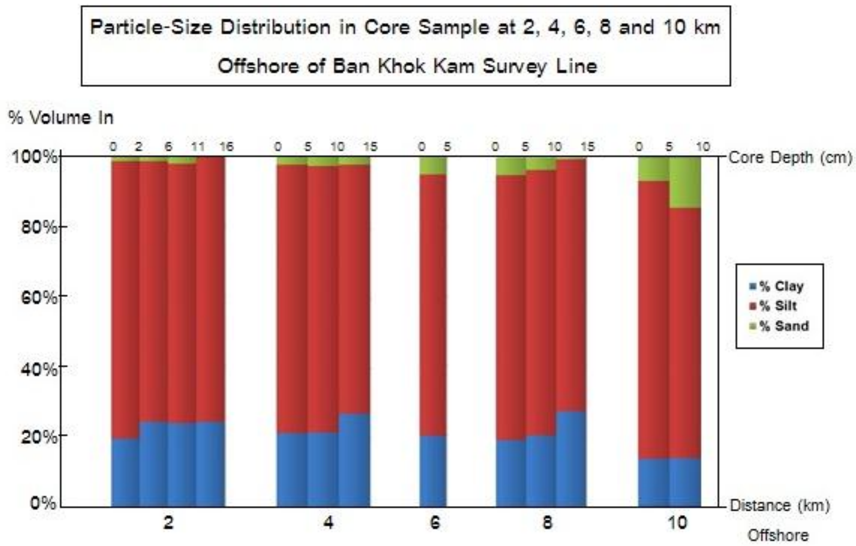


**Figure 34** Particle-size distributions in core samples at 2, 4, 6, 8, and 10 km offshore of Ban Khok Kam survey line.

### 4.4.3 Cs-137 Concentration

In this study, Cs-137 concentration represents a tracer for determining sediment erosion and sediment movement that indicated the distance or point that sediments which contain Cs-137 were transported (Grzegorz (2006)). The high concentration of Cs-137 coincides with deposition of sediment that occur after the nuclear explosions while the low concentration of Cs-137 coincides with the erosion since the sediment was gradually eroded to offshore area (Exeter (2013; Kanai et al. (2013)).

The result of Cs-137 concentrations at Ban Klong Tamru survey line is shown in Figure 35. The core samples were taken to verify the erosion of the seafloor by Cs-137 concentration at 2 layers, 0 – 5 and 5 – 10 cm depth. Theoretically, Cs-137 is concentrated in the top, 0 – 5 cm depth, for undisturbed surface areas and from the top to the deeper layer, 0 – 10 cm depth, for disturbed surface areas (Grzegorz (2006)). However, our study areas is in the intertidal zones where the tides and wave disturbs surface areas (Parks (2015)).

The result of Cs-137 concentration at Ban Khun Samut Chin survey line suggests that the top of layer, 0 – 5 cm depth, of all core samples have higher Cs-137 concentrations than the deeper layer, 5 – 10 cm depth. The exception is at 1 km offshore where the top layer has lower value than the deeper layer. The value in the top layer is below the lower limit of detection, in other words, it is below the background value. The reason for the low value is that, the top layer of the core sample at 1 km offshore of Ban Khun Samut Chin consists of higher percent of sand than others layer. Due to the fact that Cs-137 isotopes have high affinity to fine soil particles at the ground surfaces (Blagoeva and Zikovsky (1995; Exeter (2013; Grzegorz (2006; Kanai et al. (2013)), Cs-137 does not have high affinity in that layer which has high percent of sand. For the core samples at 1 - 2 km offshore, the Cs-137 concentrations show low values in comparison to others sample. The Cs-137 concentration is lower than the detection limit. These findings are conform with the study of Cs-137 concentration at the middle of Ban Khun Samut Chin survey line (Saito et al. (2013)). The core samples were taken to verify by Cs-137 concentration at depths of 0 to 4 cm. At 3 km offshore, the activities in average is approximately 0.0008 Bq/g while at 8 km offshore, the activity in average is approximately 0.0025 Bq/g. The value of Cs-137 in core sample at 3 km offshore from Saito et al. (2013) which is conform with that at 1 – 2 km offshore in our study revealed that Cs-137 concentration is lower than the detection limit. It is suspected that the areas at around 0 to 3 km offshore have been eroded. On the other hand, in the core samples from 4 km offshore, the Cs-137 concentrations show the high values. For example at 4 km offshore, the Cs-137 concentration shows the level of 0.003 Bq/g at the top layer of the core sample at 4 km offshore, and from 8 km offshore from Saito et al. (2013), the Cs-137 concentration show the level of 0.0008 Bq/g. It is believed that the areas from 4 km offshore have been redeposited. Hence, the sediments are eroded near the shore or at 1 – 2 km offshore and redeposited on seafloor from 4 km offshore.

At Ban Klong Tamru survey line, the collected samples are too few clearly to determine the points of erosion and deposition. The Cs-137 concentration is lower than the detection limit in most samples. The exception is the lower layer of the core sample at 10 km offshore. In that layer, the Cs-137 concentration is slightly higher than the detection limit. However, it is not clear enough to indicate the point of erosion in these areas because the collected sediments in this survey line are mainly consisted of sand which causes the difficulty for observing Cs-137 in the sediments (Exeter (2013)). The result of Cs-137 concentrations at Ban Klong Tamru survey line is shown in Figure 36.

At Ban Khok Kam survey line, the obviously high values of Cs-137 are in the core samples at 4, 6 and 8 km offshore. Sometimes, the value of Cs-137 concentration in the lower layer is higher than that at the top layer (at 8 km offshore). This is due to the fact that the seafloor of this area is disturbed by wave and tides (Grzegorz (2006)). All samples from around 3 km offshore have higher values of Cs-137 concentration than the detection limit. The exception is at 2 km offshore where the value is low. Therefore, it is suspected that the areas from 3 km offshore are redeposited while the areas at around 0 - 2 km offshore are eroded. The result of Cs-137 concentrations at Ban Khok Kam survey line is shown in Figure 37.

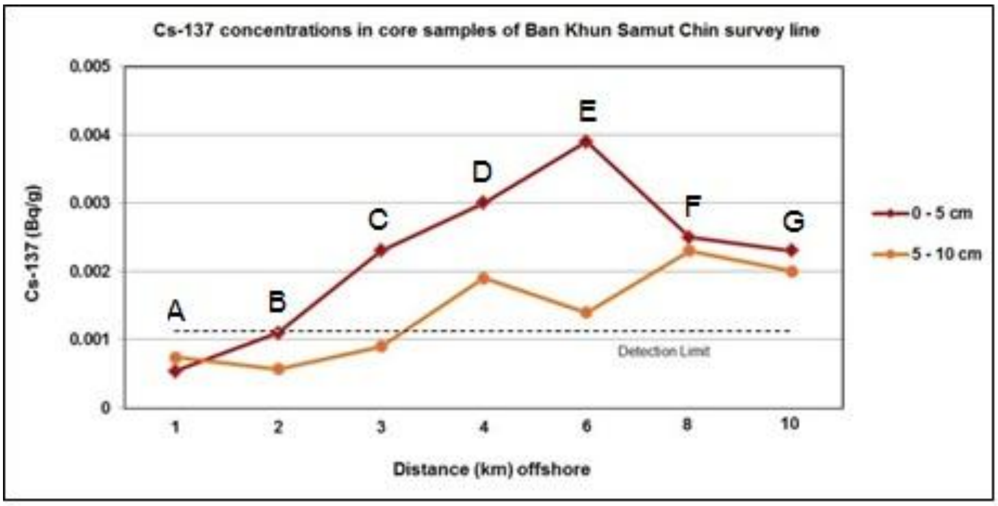


**Figure 35** Cs-137 concentrations in core samples of Ban Khun Samut Chin survey line.

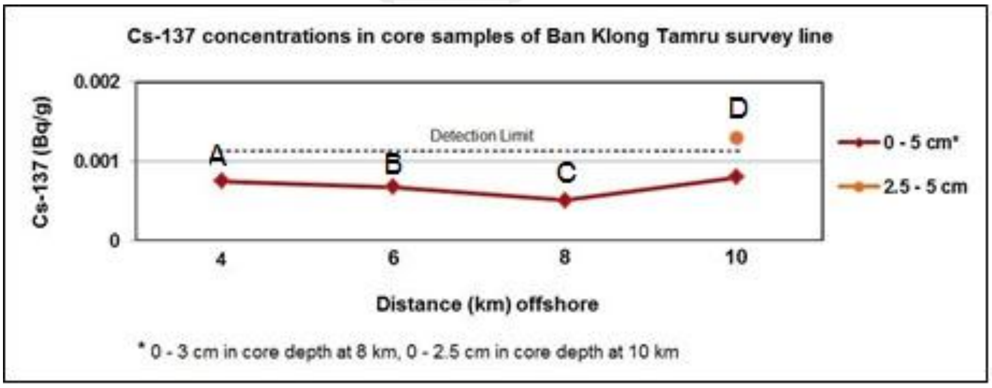


**Figure 36** Cs-137 concentrations in core samples of Ban Klong Tamru survey line.

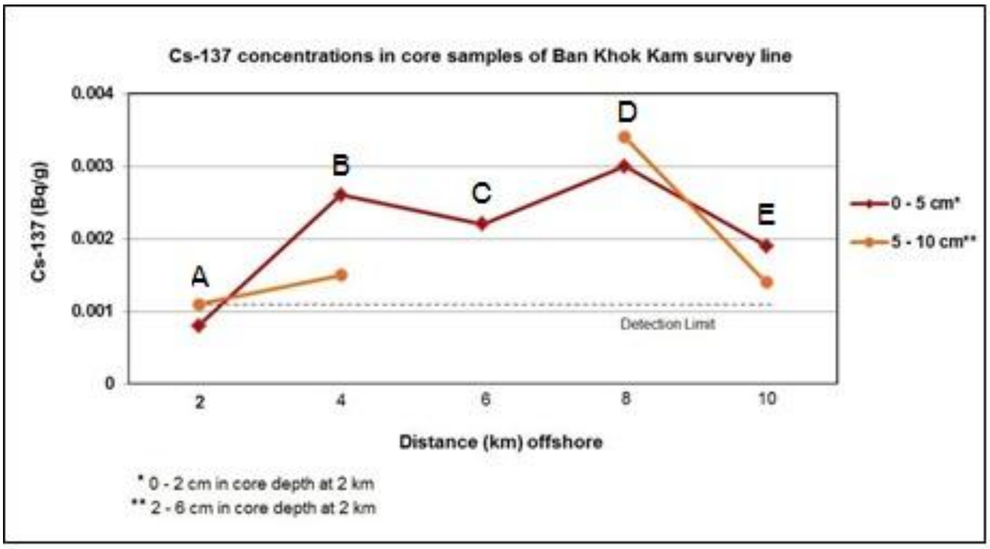


**Figure 37** Cs-137 concentrations in core samples of Ban Khok Kam survey line.

# CHAPTER V

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

The comparison among the bathymetric profiles in the study area, three survey lines, during NE monsoon season illustrates an extreme change on the coasts in the scale of approximately 10 years. However, in the short time scale, less than 4 years, the change in the coastal bathymetry is not obvious. From these results, the coastal erosion occurs in the study area, but it is hard to observe in the short time scale. The bathymetric maps show that the seafloor elevation from the coasts to 12 km offshore is between 0 to - 7 m (LLW) and the sonographs show that the muddy coast of the study area is consisted of soft materials. From the result of particle-size distribution, most sediments are silt loam except at Ban Klong Tamru survey line where high percentage of sand is found in the sediments. The result of water content in the sediment reveals that the water content is lower in the deeper soil layer but higher in the farther offshore area. This finding shows that at 0 – 6 km offshore at Ban Khun Samut Chin survey line, at 0 – 10 km offshore at Ban Klong Tamru survey line, and at 0 – 8 km offshore at Ban Khok Kam survey line, the water contents are low. These low water contents suggest that the area is consisted of stiff mud or primitive sediment. On the other hand, at the farther offshore areas, the water contents show high values. These high water contents suggest that the area is consisted of soft mud or non-primitive sediment. At both Ban Khun Samut Chin and Ban Khok Kam survey lines which are on the west side of the Chao Phraya River mouth, sediments are mostly consisted of clay and silt, while percentage of sand is small, but at Ban Klong Tamru survey line which is located on the east side of the Chao Phraya River mouth, sediments are consisted of sand for 50 percent or more. Since this area is near the sedimental transporting route of the estuary, this high percentage of sand is suspected to be the bedload of the Chao Phraya River. The Cs-

137 concentrations show low values in the sediments collected near the coasts or around 0 to 2 km offshore of Ban Khun Samut Chin and Ban Khok Kam survey lines. As a result, it is suspected that there has been eroded near the coast. On the other hand, the sediments collected far away or from around 3 km offshore have higher level of Cs-137. As a result, it is suspected that there has been redeposited in this area. However, at Ban Klong Tamru survey line, the collected samples are too few clearly to determine the points of erosion and deposition. As a result, it is suspected that most of the sediments are consisted of sand which causes the difficulty for Cs-137 to be detected.

## 5.2 Recommendations

This study has found that at Ban Klong Tamru survey line, the sediments in core samples have high percent of sand which make it difficult to collect samples by the gravity core, so collecting samples by other method may be better in order to recover more samples and lead to better result. Moreover, due to the limitation of the instrument availability, sampling cannot be done in one time and the instrument used in each time are not the same. A large gravity core with 10 cm diameter was used for the first survey at Ban Khun Samut Chin line, while a small gravity core with 4 cm diameter was used for the second survey at two other lines. If we use 10 cm diameter core at every locations of sampling, it would be possible to collect more sediments. Having more amount of sediments would also benefit this study in dating Cs-137 isotopes which requires sediment samples volume of at least 50 g for each location. Not only for dating Cs-137, more sediment samples will also be adequate for determining Pb-210 concentration which allow us to determine the accumulation rate of sediments. In this study the result of sonographs are not clear to distinguish the areas where zone of stiff muds or soft muds. However, the result of sonographs can represent the overall sediment characteristics in the seafloor. For the determination of percent water content which can be used as preliminary indicator of the erosion, the result from this study found that the layer at

5 – 10 cm of sediment collected by a gravity core gives desirable percent water content. In this study, the surveys were conducted during NE monsoon season. If the study during southwest (SW) monsoon season is conducted in addition, the results will be even better and more reliable.

For the application of this study, we can suggest that pumping the sediments from 3 km offshore or further can be considered as a measure to handle the problem of coastal erosion in the UGOT. Apart from the UGOT, similar method to this study can also be applied in studying the muddy coasts and solve the erosion problem in other areas with similar condition to the study area.

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# APPENDICES

# APPENDIX A

## SURVEYING COORDINATES

**Table 5** The coordinates which were recorded from echo-sounding and side-scan survey at Ban Klong Tamru survey line on 5th December 2012.

| ID | EAST | NORTH |
|---|---|---|
| 1 | 680334.6 | 1493211 |
| 2 | 679616.8 | 1491514 |
| 3 | 679138.3 | 1490470 |
| 4 | 679943.1 | 1490166 |
| 5 | 679029.6 | 1490014 |
| 6 | 679508.1 | 1489165 |
| 7 | 678355.3 | 1488426 |
| 8 | 677833.3 | 1487382 |
| 9 | 678355.3 | 1486425 |
| 10 | 677267.8 | 1485838 |
| 11 | 677137.3 | 1485707 |
| 12 | 676463.1 | 1483945 |

**Table 6** The coordinates which were recorded from echo-sounding and side-scan survey at Ban Khun Samut Chin survey line on 4th December 2012.

| ID | EAST | NORTH |
|---|---|---|
| 1 | 665818.2 | 1493443 |
| 2 | 665968.9 | 1492852 |
| 3 | 666050 | 1492694 |
| 4 | 666146.5 | 1492365 |
| 5 | 666262.4 | 1491628 |
| 6 | 666656.4 | 1489156 |
| 7 | 666873.4 | 1488136 |
| 8 | 667220.6 | 1487181 |
| 9 | 667198.9 | 1486161 |
| 10 | 667481 | 1484686 |
| 11 | 667828.2 | 1483666 |
| 12 | 667716.2 | 1483509 |

**Table 7** The coordinates which were recorded from echo-sounding and side-scan survey at Ban Khok Kam survey line on 6th December 2012.

| ID | EAST | NORTH |
|---|---|---|
| 1 | 646973.33 | 1490878.28 |
| 2 | 647896.26 | 1490999.72 |
| 3 | 647070.48 | 1489566.75 |
| 4 | 648114.85 | 1489518.17 |
| 5 | 647240.49 | 1487939.48 |
| 6 | 648333.43 | 1487137.99 |
| 7 | 647459.08 | 1485437.85 |
| 8 | 648552.02 | 1484709.23 |
| 9 | 647556.23 | 1483762.01 |
| 10 | 648697.75 | 1483373.41 |
| 11 | 647701.96 | 1482110.45 |
| 12 | 648916.34 | 1481381.82 |

**Table 8** The coordinates which were recorded from sediment sampling at Ban Khun Samut Chin survey line on 28th November 2013.

| ID | EAST | NORTH |
|---|---|---|
| 1 | 666189.12 | 1492477.83 |
| 2 | 666354.27 | 1491526.25 |
| 3 | 666571.46 | 1490583.57 |
| 4 | 666308.47 | 1489535.56 |
| 5 | 666151.6 | 1487477.8 |
| 6 | 666408.42 | 1485431.83 |
| 7 | 666919.97 | 1483378.6 |

**Table 9** The coordinates which were recorded from sediment sampling at Ban Klong Tamru survey line on 25th November 2014.

| ID | EAST | NORTH |
|---|---|---|
| 1 | 679202.83 | 1489668.96 |
| 2 | 678607 | 1487739.11 |
| 3 | 677957.87 | 1485854.43 |
| 4 | 676901.24 | 1484102.06 |

**Table 10** The coordinates which were recorded from sediment sampling at Ban Khok Kam survey line on 25th November 2014.

| ID | EAST | NORTH |
|---|---|---|
| 1 | 647683.63 | 1489057.29 |
| 2 | 647456.26 | 1486775.88 |
| 3 | 647787.16 | 1484975.92 |
| 4 | 648280.46 | 1483028.8 |
| 5 | 648075.93 | 1480847.29 |

# APPENDIX B

# ELEVATION AND BATHYMETRIC MAPS

**Table 11** The elevation (m, LLW) and the distance (km) offshore of Ban Khun Samut Chin survey line which were obtained from echo-sounding surveys and the contour lines from bathymetric maps (HDRTN) in the years 1960, 1972, 1984, 1988, 1999, 2008, 2010 and 2012.

| Year | Distance (km) offshore | Elevation (m, LLW) |
|---|---|---|
| 1960 | 0 | 3.3 |
| | 1 | 3 |
| | 2 | 1.5 |
| | 3 | -1 |
| | 4 | -2 |
| | 5 | -2.5 |
| | 6 | -3 |
| | 7 | -3.8 |
| | 8 | -4.2 |
| | 9 | -4.6 |
| | 10 | -5.3 |
| | 11 | -5.8 |
| | 12 | -6 |
| 1972 | 0 | 3 |
| | 1.4 | 1.8 |
| | 2 | 0.6 |
| | 3.4 | -1.8 |
| | 4 | -2.3 |
| | 4.5 | -2.5 |
| | 5.1 | -2.7 |
| | 5.8 | -3 |
| | 6.5 | -3.5 |
| | 7.3 | -3.9 |
| | 7.7 | -4.2 |
| | 8.3 | -4.3 |
| | 9.2 | -4.7 |
| | 10 | -5.4 |
| | 12 | -6.2 |
| 1984 | 0 | 2.8 |
| | 1 | 1.8 |
| | 2 | -0.2 |
| | 3 | -1.7 |
| | 5.2 | -3 |
| | 6.8 | -3.9 |
| | 7.8 | -4.4 |
| | 8.5 | -4.6 |
| | 9 | -4.8 |
| | 12 | -6.2 |
| 1988 | 0 | 2.77 |
| | 1.1 | 1.3 |
| | 3.2 | -2 |
| | 4.2 | -2.5 |
| | 6.2 | -3.5 |
| | 8.3 | -4.4 |
| | 12 | -6.3 |
| 1999 | 0 | 2.5 |
| | 1 | 0.8 |

| | | |
|---|---|---|
| | 1.4 | -0.1 |
| | 2.2 | -1.2 |
| | 3 | -2 |
| | 4.4 | -2.8 |
| | 5.3 | -3.4 |
| | 6.3 | -3.6 |
| | 7.9 | -4.5 |
| | 9.1 | -5.2 |
| | 12 | -6.4 |
| 2008 | 0 | 1.9 |
| | 1 | -0.1 |
| | 2 | -1.7 |
| | 3 | -2.4 |
| | 4 | -3 |
| | 5 | -3.8 |
| | 6 | -4.1 |
| | 7 | -4.3 |
| | 8 | -5 |
| | 9 | -5.5 |
| | 10 | -5.9 |
| | 11 | -6.3 |
| | 12 | -6.8 |
| 2010 | 0 | 1.8 |
| | 1 | 0 |
| | 2 | -1.7 |
| | 3 | -2.5 |
| | 4 | -3 |
| | 5 | -3.8 |
| | 6 | -4 |
| | 7 | -4.2 |
| | 8 | -5 |
| | 9 | -5.5 |
| | 10 | -6 |
| | 11 | -6.3 |
| | 12 | -6.8 |
| 2012 | 0 | 1.8 |
| | 1 | -0.2 |
| | 2 | -1.8 |
| | 3 | -2.6 |
| | 4 | -3 |
| | 5 | -3.9 |
| | 6 | -4 |
| | 7 | -4.3 |
| | 8 | -5 |
| | 9 | -5.6 |
| | 10 | -5.9 |
| | 11 | -6.2 |
| | 12 | -6.8 |

0 m = lowest low water level

**Table 12** The elevation (m, LLW) and the distance (km) offshore of Ban Klong Tamru survey line which were obtained from echo-sounding surveys and the contour lines from bathymetric maps (HDRTN) in the years 1960, 1972, 1984, 1988, 1999, 2008, 2010 and 2012.

| Year | Distance (km) offshore | Elevation (m, LLW) |
|---|---|---|
| 1960 | 0 | 2.5 |
| | 1 | 1.8 |
| | 2 | 1.5 |
| | 3 | 1 |
| | 4 | 0.5 |
| | 5 | 0 |
| | 6 | -0.5 |
| | 7 | -1 |

| | | |
|---|---|---|
| | 8 | -2 |
| | 9 | -3 |
| | 10 | -4.7 |
| | 11 | -6 |
| | 12 | -7 |
| 1972 | 0 | 2.4 |
| | 2.7 | 0.7 |
| | 6.7 | -1 |
| | 8.2 | -2 |
| | 9.3 | -3.2 |
| | 11 | -6 |
| | 12 | -7 |
| 1984 | 0 | 2.35 |
| | 2 | 0.4 |
| | 5 | -1 |
| | 6.7 | -1.5 |
| | 8.4 | -2.3 |
| | 9 | -3.2 |
| | 11 | -6 |
| | 12 | -7 |
| 1988 | 0 | 2.3 |
| | 2 | 0.46 |
| | 5 | -1 |
| | 8 | -2.1 |
| | 12 | -7 |
| 1999 | 0 | 2.3 |
| | 1 | 1 |
| | 2 | -0.3 |
| | 3 | -0.6 |
| | 6.9 | -1.6 |
| | 9 | -3.4 |
| | 11 | -6 |
| | 12 | -7 |
| 2008 | 0 | 2.1 |
| | 1 | 0 |
| | 2 | -0.7 |
| | 3 | -1 |
| | 4 | -1.2 |
| | 5 | -1.8 |
| | 6 | -2 |
| | 7 | -2 |
| | 8 | -2.6 |
| | 9 | -4 |
| | 10 | -5 |
| | 11 | -6 |
| | 12 | -7 |
| 2010 | 0 | 2 |
| | 1 | -0.1 |
| | 2 | -0.7 |
| | 3 | -1 |
| | 4 | -1.2 |
| | 5 | -1.7 |
| | 6 | -2 |
| | 7 | -2.1 |
| | 8 | -2.6 |
| | 9 | -4 |
| | 10 | -5 |
| | 11 | -6 |
| | 12 | -7 |
| 2012 | 0 | 2 |
| | 1 | -0.2 |
| | 2 | -0.8 |
| | 3 | -1 |
| | 4 | -1.1 |
| | 5 | -1.77 |
| | 6 | -2 |
| | 7 | -2.3 |
| | 8 | -2.7 |
| | 9 | -3.8 |
| | 10 | -5 |

| | | |
|---|---|---|
| | 11 | -6 |
| | 12 | -7 |

0 m = lowest low water level

**Table 13** The elevation (m, LLW) and the distance (km) offshore of Ban Khok Kam survey line which were obtained from echo-sounding surveys and the contour lines from bathymetric maps (HDRTN) in the years 1960, 1980, 1988, 2004, 2008, 2010 and 2012.

| Year | Distance (km) offshore | Elevation (m, LLW) |
|---|---|---|
| 1960 | 0 | 3.3 |
| | 1 | 1.2 |
| | 2 | -0.6 |
| | 3 | -1.3 |
| | 4 | -2 |
| | 5 | -3 |
| | 6 | -4 |
| | 7 | -4.5 |
| | 8 | -5 |
| | 9 | -5.5 |
| | 10 | -6 |
| | 11 | -6.2 |
| | 12 | -6.5 |
| 1980 | 0 | 2.74 |
| | 0.7 | 1 |
| | 1.2 | -0.3 |
| | 1.9 | -1 |
| | 2.3 | -1.4 |
| | 4.2 | -3 |
| | 5.7 | -4 |
| | 7.6 | -5 |
| | 12 | -6.7 |
| 1988 | 0 | 2.47 |
| | 1 | -0.2 |
| | 2 | -1.5 |
| | 3.7 | -2.7 |
| | 5.8 | -4.2 |
| | 7.5 | -5 |
| | 9 | -5.7 |
| | 12 | -6.8 |
| 2004 | 0 | 2.24 |
| | 0.95 | -1 |
| | 1.3 | -1.5 |
| | 4.7 | -3.8 |
| | 6.9 | -5 |
| | 8.8 | -5.8 |
| | 12 | -7 |
| 2008 | 0 | 2 |
| | 1 | -1.6 |
| | 2 | -2.3 |
| | 3 | -3 |
| | 4 | -3.8 |
| | 5 | -4.1 |
| | 6 | -5 |
| | 7 | -5.4 |
| | 8 | -6 |
| | 9 | -6.2 |
| | 10 | -6.4 |
| | 11 | -6.6 |
| | 12 | -7 |
| 2010 | 0 | 2 |
| | 1 | -1.7 |
| | 2 | -2.3 |
| | 3 | -3.1 |
| | 4 | -3.8 |
| | 5 | -4.2 |

| | | |
|---|---|---|
| | 6 | -5 |
| | 7 | -5.5 |
| | 8 | -6 |
| | 9 | -6.3 |
| | 10 | -6.5 |
| | 11 | -6.7 |
| | 12 | -7 |
| 2012 | 0 | 2 |
| | 1 | -1.7 |
| | 2 | -2.3 |
| | 3 | -3.2 |
| | 4 | -3.8 |
| | 5 | -4.2 |
| | 6 | -5 |
| | 7 | -5.6 |
| | 8 | -6.1 |
| | 9 | -6.3 |
| | 10 | -6.5 |
| | 11 | -6.7 |
| | 12 | -7 |

0 m = lowest low water level


**Figure 38** Bathymetric map of Ban Khun Samut Chin line (Suthisanonth et al. (2015)). Sonograph data is derived from Geological Survey of Japan (2012).

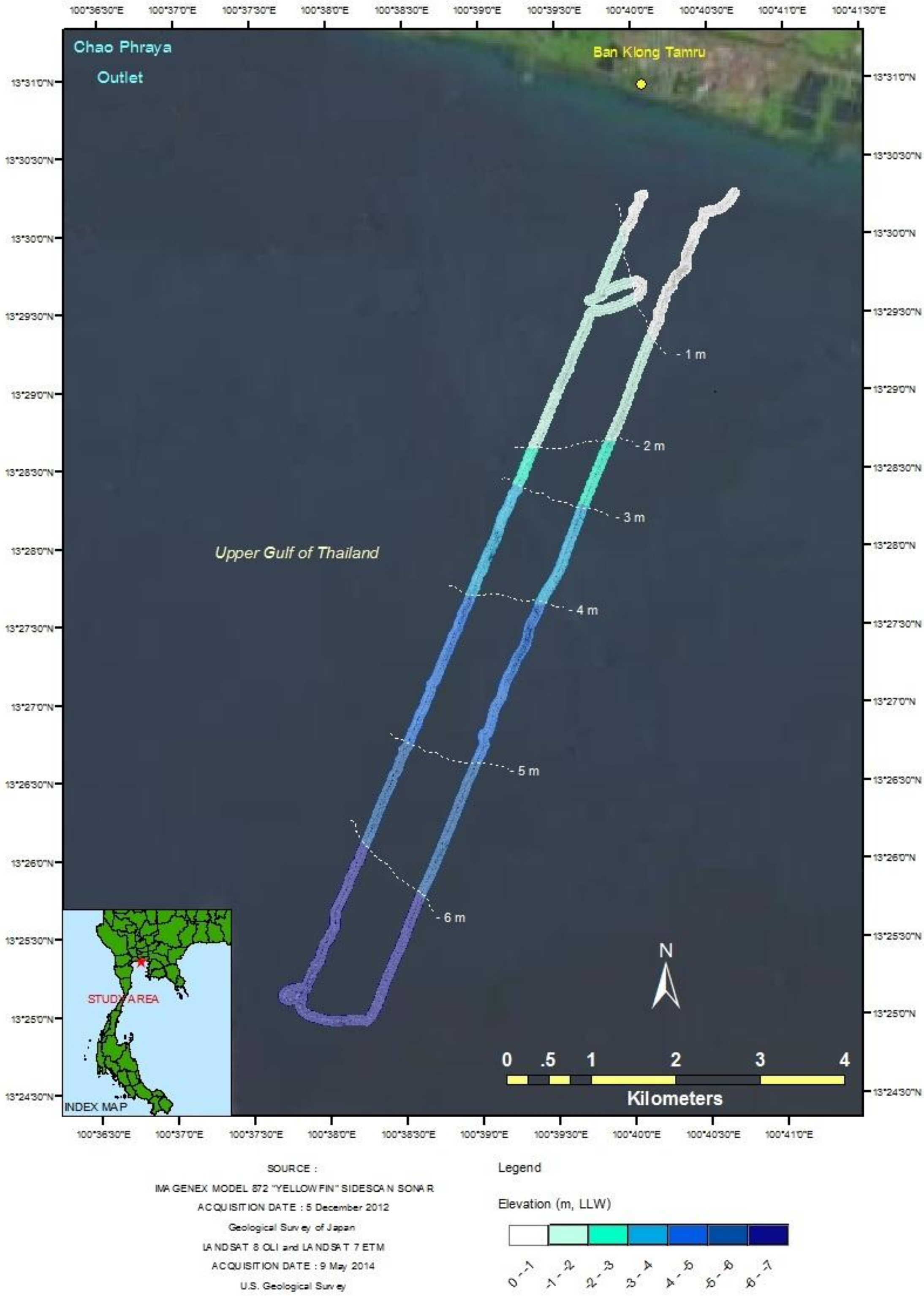



**Figure 39** Bathymetric map of Ban Klong Tamru line (Suthisanonth et al. (2015)). Sonograph data is derived from Geological Survey of Japan (2012).

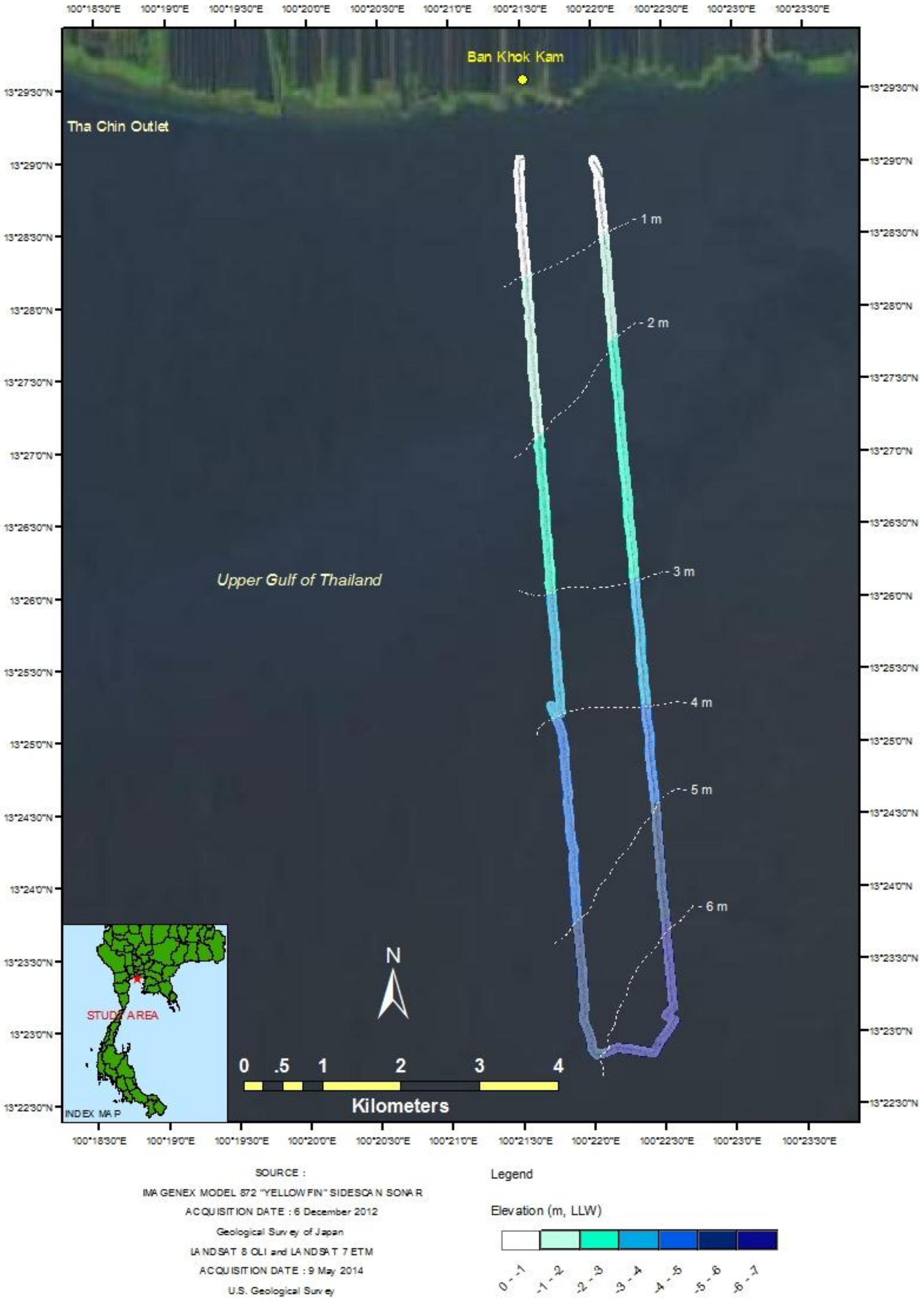



**Figure 40** Bathymetric map of Ban Khok Kam line (Suthisanonth et al. (2015)). Sonograph data is derived from Geological Survey of Japan (2012).

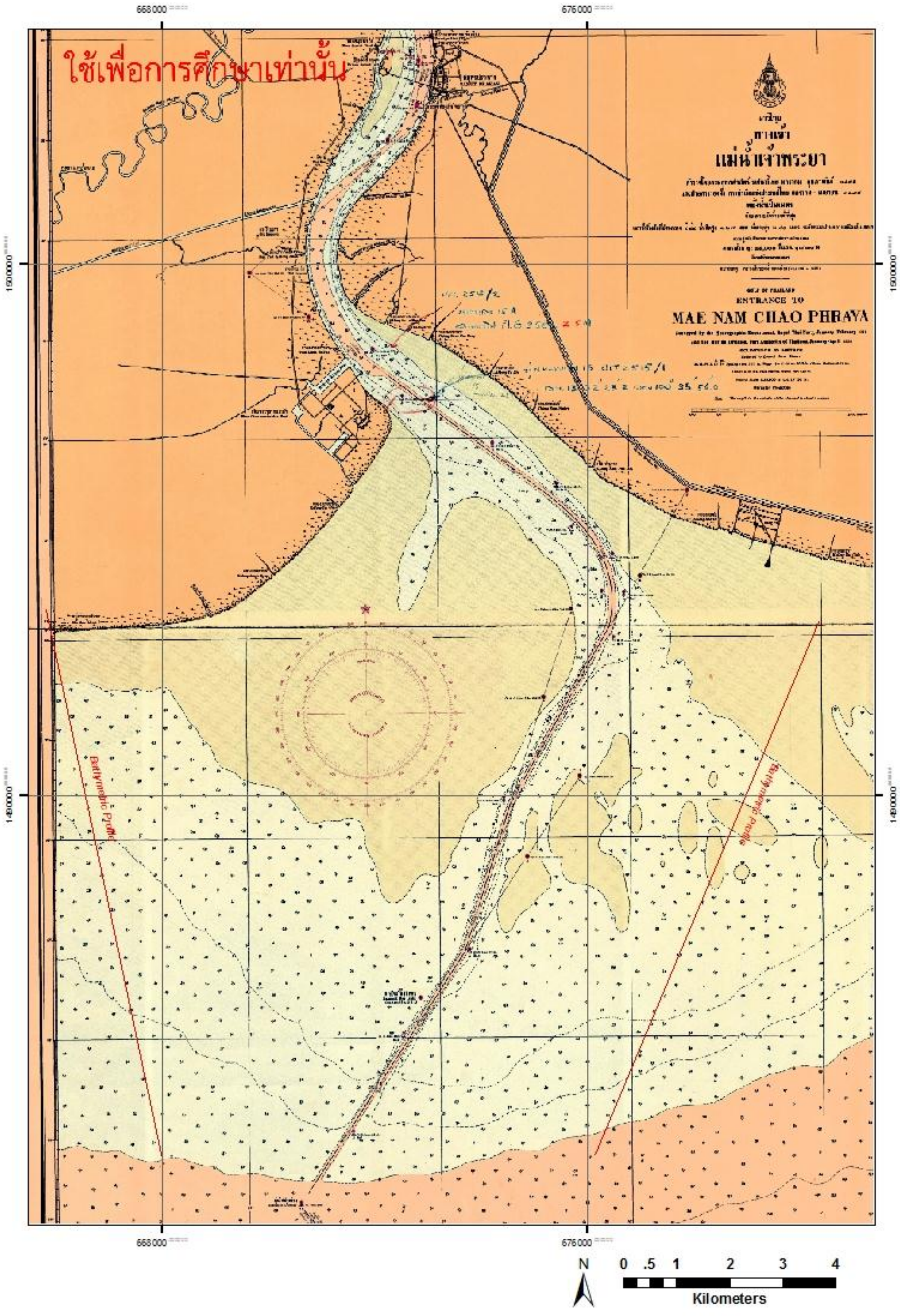



**Figure 41** Nautical map in the year 1972 (HDRTN).

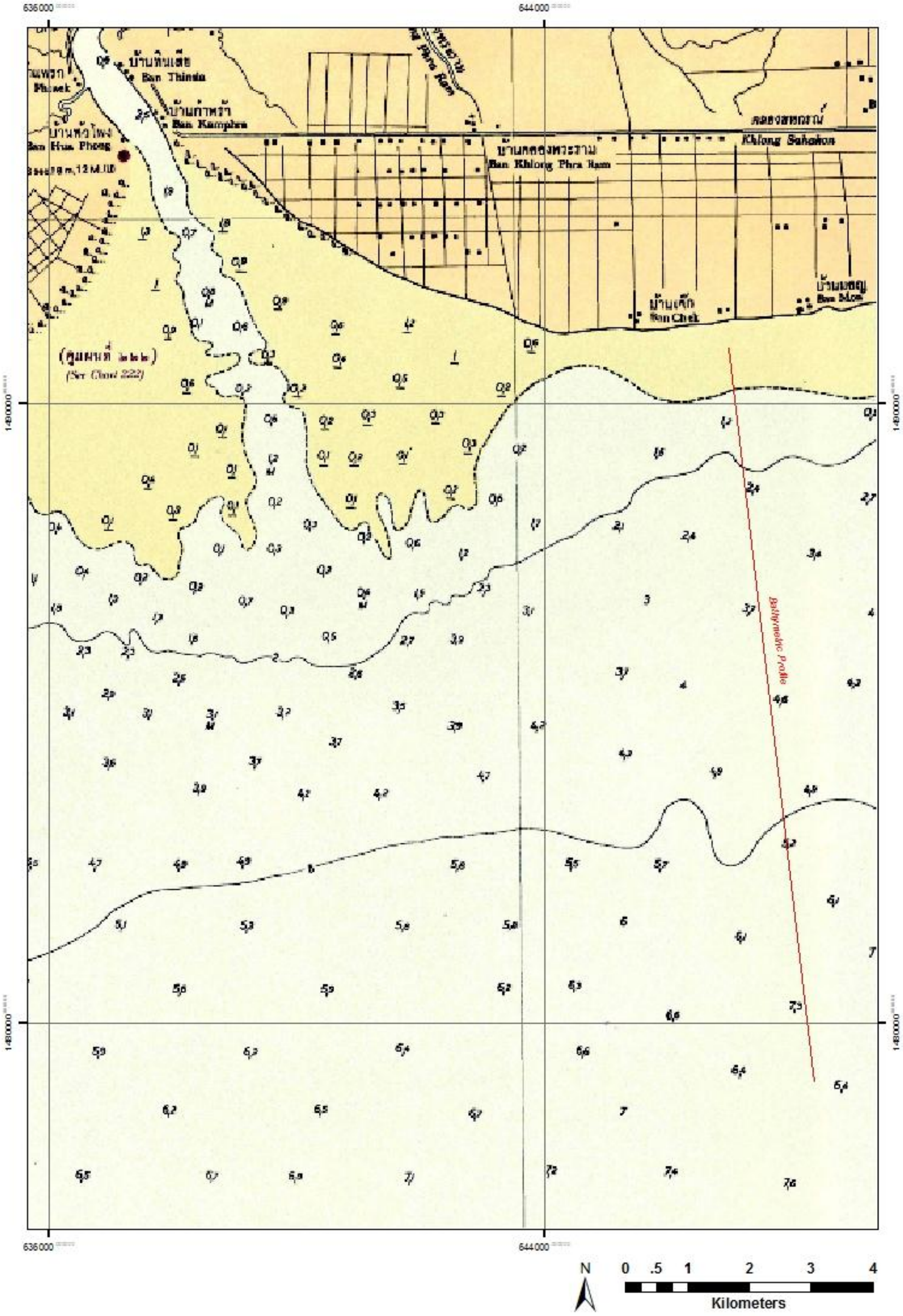



**Figure 42** Nautical map in the year 1980 (HDRTN).

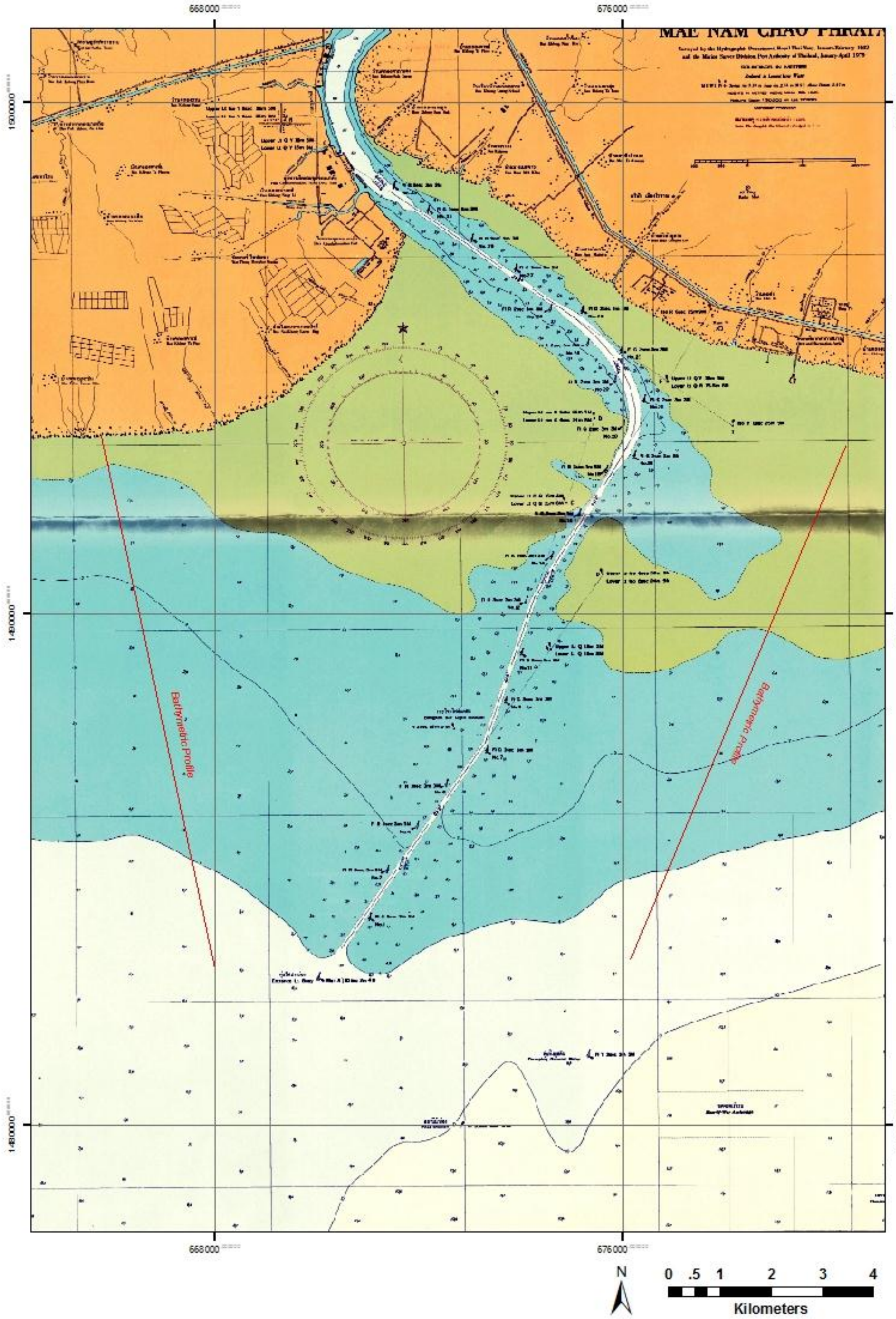



**Figure 43** Nautical map in the year 1984 (HDRTN).

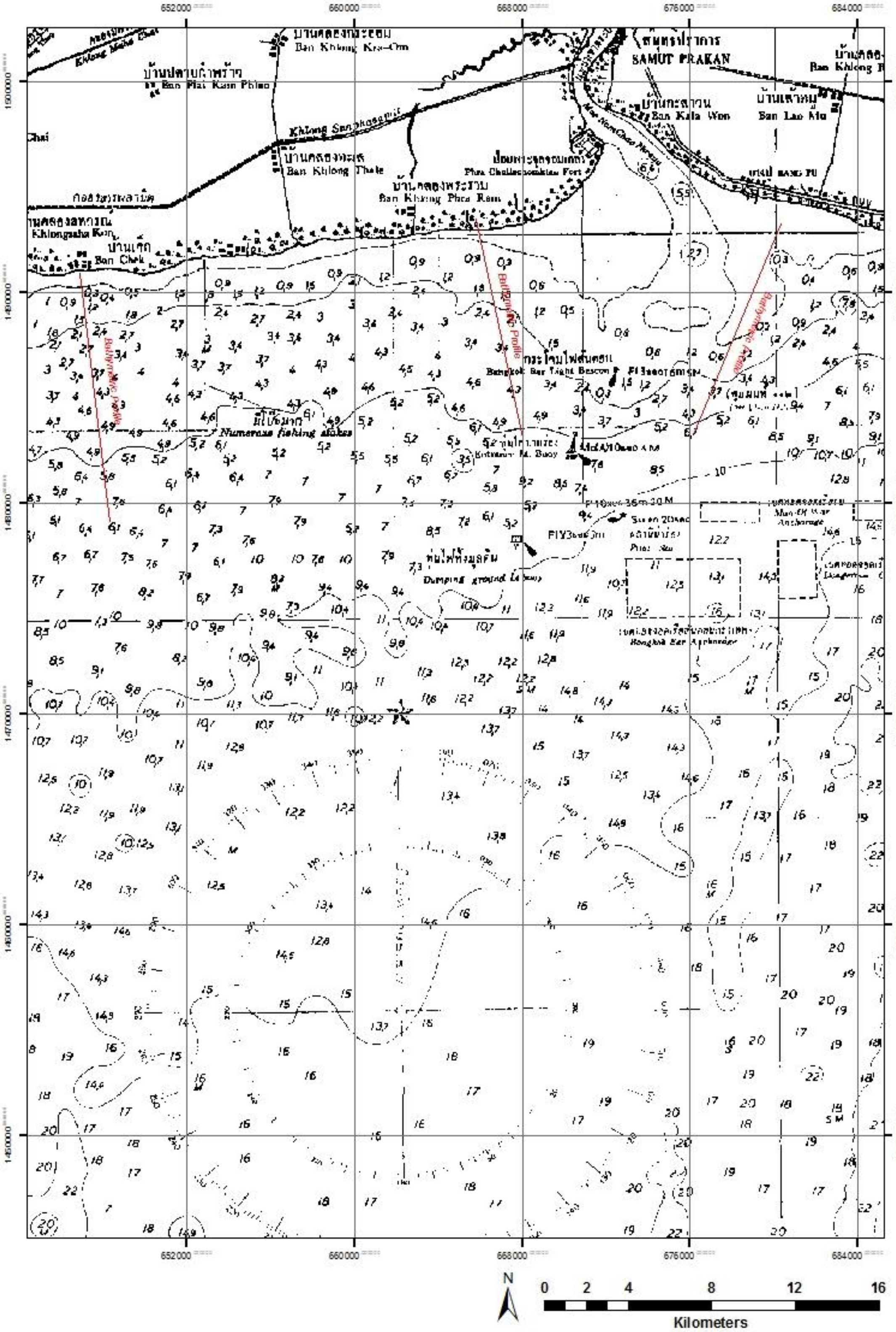



**Figure 44** Nautical map in the year 1988 (HDRTN).

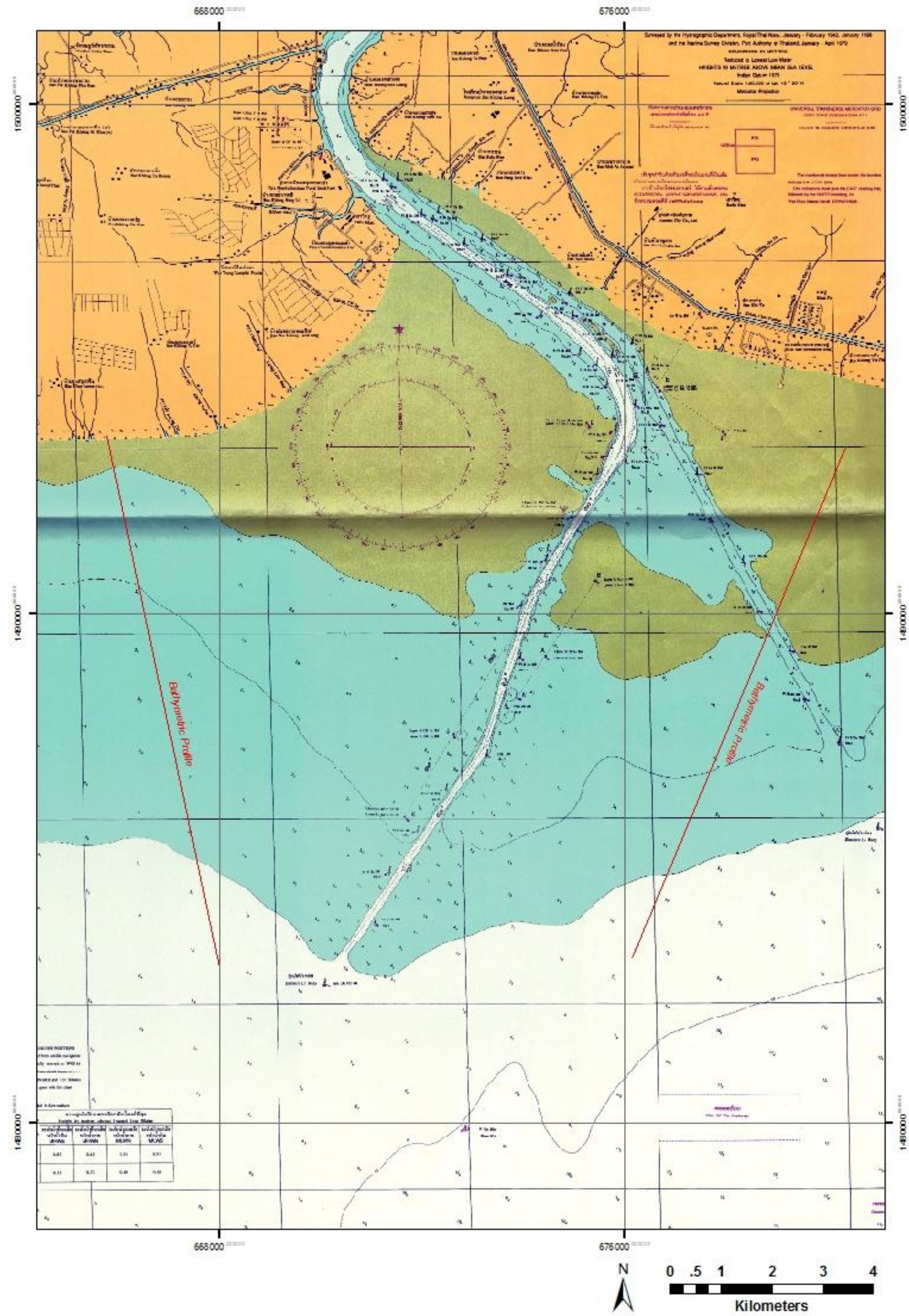



**Figure 45** Nautical map in the year 1999 (HDRTN).

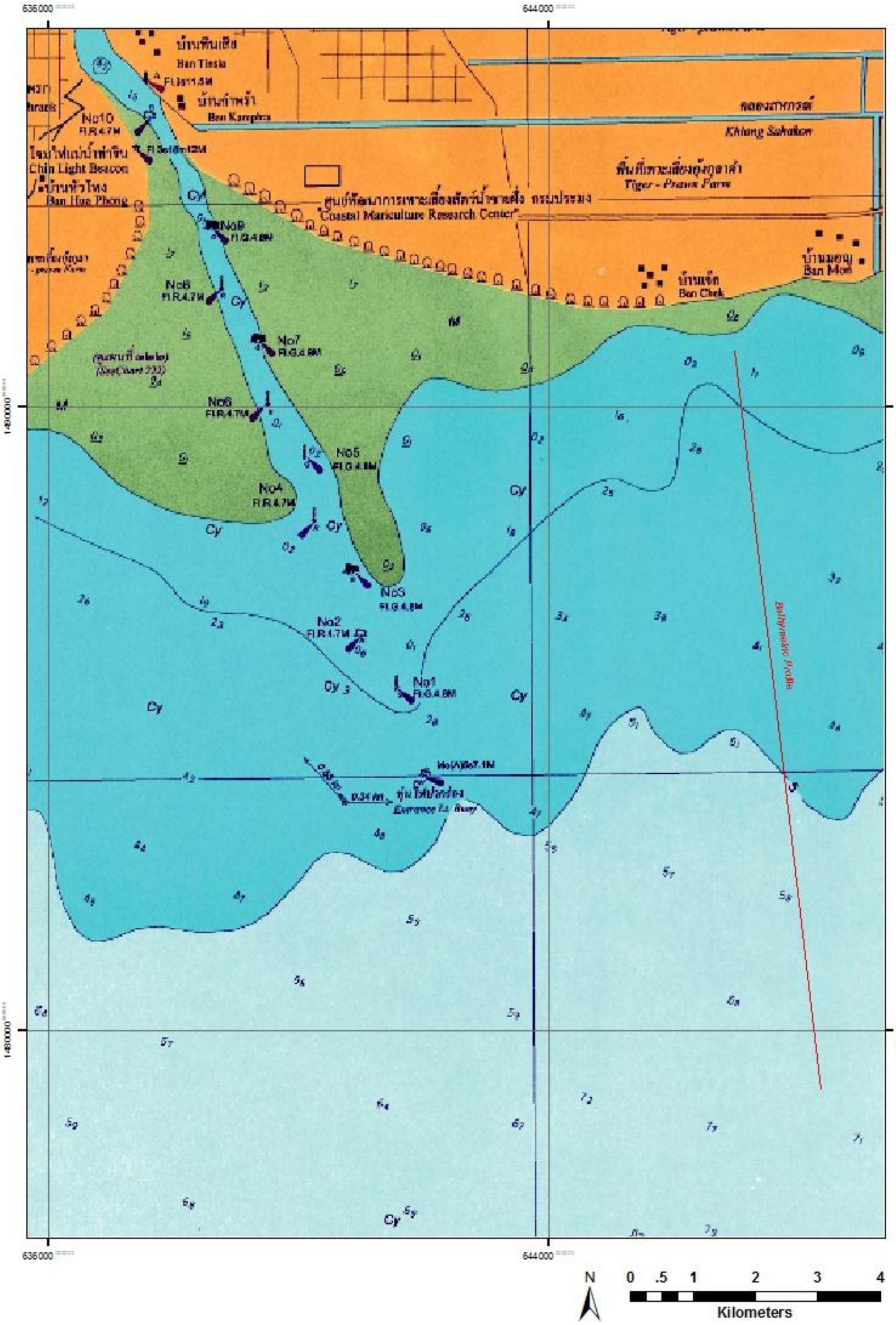



**Figure 46** Nautical map in the year 2004 (HDRTN).

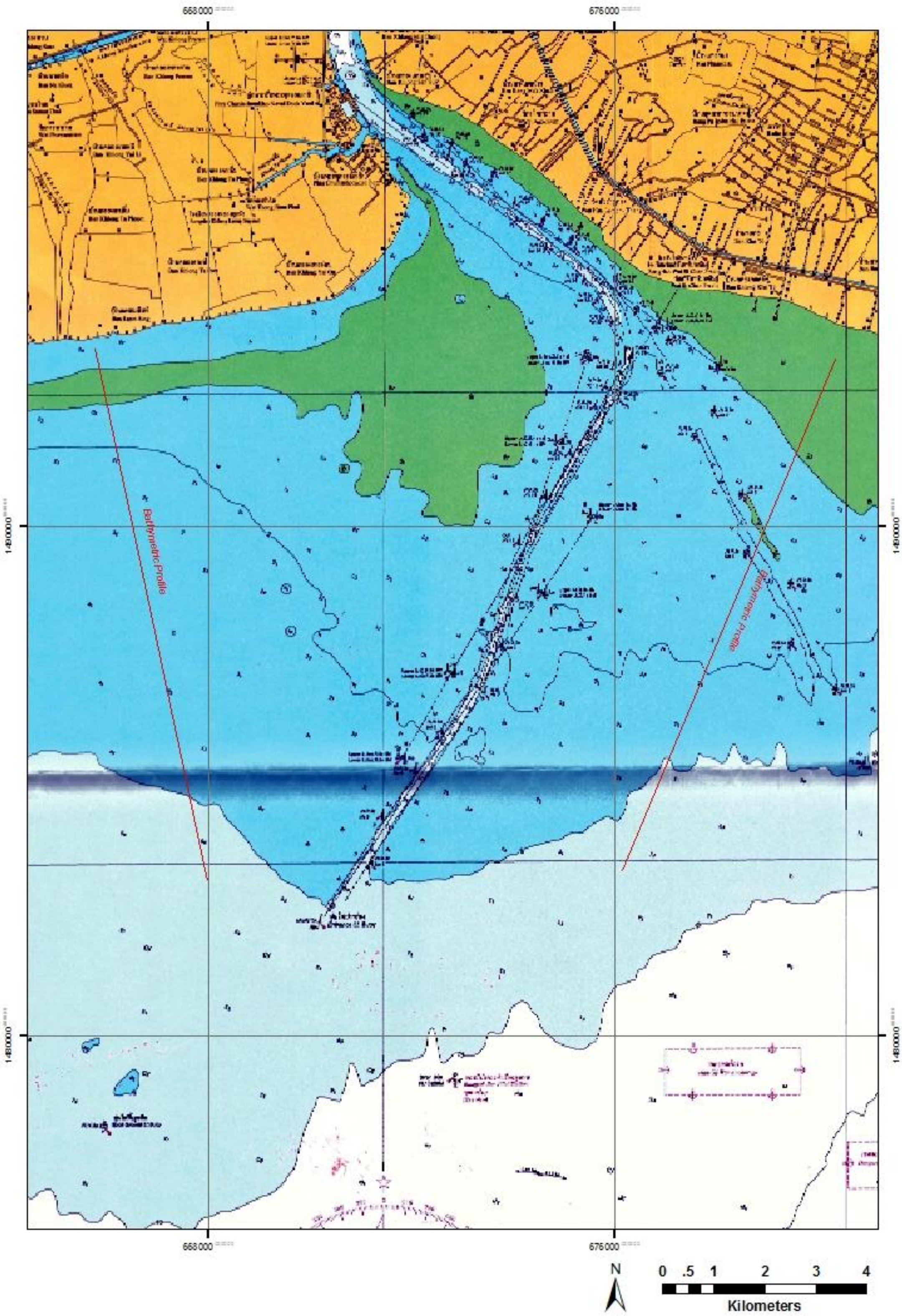



**Figure 47** Nautical map in the year 2008 (HDRTN).

# APPENDIX C

## PERCENT OF WATER CONTENT

**Table 14** Water content in each core sample of Ban Khun Samut Chin, Ban Klong Tamru and Ban Khok Kam survey lines.

| Survey Line | Distance (km) Offshore | Point | Core Depth (cm) | Sample No. | % Water Content |
|---|---|---|---|---|---|
| Ban Khun Samut Chin | 1 | A | 0 - 5 | 1 | 61.32 |
| | | | 5 - 10 | 2 | 55.6 |
| | | | 10 - 15 | 3 | 49.1 |
| | 2 | B | 0 - 5 | 4 | 65.7 |
| | | | 5 - 10 | 5 | 58.16 |
| | | | 10 - 15 | 6 | 50.64 |
| | | | 15 - 20 | 7 | 48.74 |
| | 3 | C | 0 - 5 | 8 | 67.04 |
| | | | 5 - 10 | 9 | 60.32 |
| | | | 10 - 15 | 10 | 53.18 |
| | | | 15 - 20 | 11 | 49.2 |
| | 4 | D | 0 - 5 | 12 | 71.09 |
| | | | 5 - 10 | 13 | 59.74 |
| | | | 10 - 15 | 14 | 55.62 |
| | | | 15 - 20 | 15 | 54.77 |
| | 6 | E | 0 - 5 | 16 | 68.28 |
| | | | 5 - 10 | 17 | 60.39 |
| | | | 10 - 15 | 18 | 58.55 |
| | | | 15 - 20 | 19 | 57.13 |
| | | | 20 - 25 | 20 | 56.74 |
| | | | 25 - 30 | 21 | 54.31 |
| | 8 | F | 0 - 5 | 22 | 74.31 |
| | | | 5 - 10 | 23 | 65.92 |
| | | | 10 - 15 | 24 | 64.5 |

| | | | | | |
|---|---|---|---|---|---|
| | | | 15 - 20 | 25 | 62.83 |
| | | | 20 - 25 | 26 | 56.75 |
| | | | 25 - 30 | 27 | 55.24 |
| | 10 | G | 0 - 5 | 28 | 78.83 |
| | | | 5 - 10 | 29 | 64.47 |
| | | | 10 - 15 | 30 | 62.56 |
| | | | 15 - 20 | 31 | 61.16 |
| | | | 20 - 25 | 32 | 59.82 |
| | | | 25 - 30 | 33 | 57.7 |
| | | | 30 - 35 | 34 | 53.84 |
| Ban Klong Tamru | 4 | A | 0 - 5 | 35 | 30.98 |
| | 6 | B | 0 - 5 | 36 | 27.42 |
| | 8 | C | 0 - 3 | 37 | 38.91 |
| | 10 | D | 0 - 2.5 | 38 | 49.19 |
| | | | 2.5 - 5 | 39 | 36.65 |
| | | | 5 - 7 | 40 | 29.91 |
| Ban Khok Kam | 2 | A | 0 - 2 | 41 | 60.1 |
| | | | 2 - 6 | 42 | 58.74 |
| | | | 6 - 11 | 43 | 56.4 |
| | | | 11 - 16 | 44 | 52.01 |
| | 4 | B | 0 - 5 | 45 | 63.47 |
| | | | 5 - 10 | 46 | 52.26 |
| | | | 10 - 15 | 47 | 46 |
| | 6 | C | 0 - 5 | 48 | 59.8 |
| | 8 | D | 0 - 5 | 49 | 58.4 |
| | | | 5 - 10 | 50 | 56.69 |
| | | | 10 - 15 | 51 | 47.58 |
| | 10 | E | 0 - 5 | 52 | 73.9 |
| | | | 5 - 10 | 53 | 66.98 |

# APPENDIX D

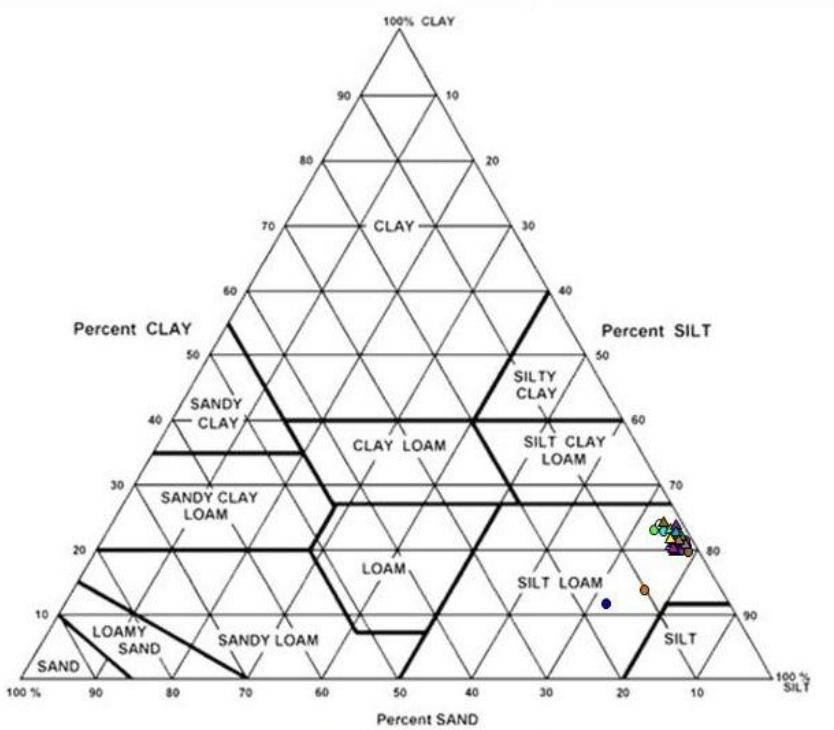
# PARTICLE-SIZE DISTRIBUTIONS

**Table 15** Particle-size distribution in each core sample of Ban Khun Samut Chin, Ban Klong Tamru and Ban Khok Kam survey lines.

| Survey Line | Distance (km) Offshore | Point | Core Depth (cm) | Sample No. | % Particle-Size | | |
|---|---|---|---|---|---|---|---|
| | | | | | % Clay | % Silt | % Sand |
| Ban Khun Samut Chin | 1 | A | 0 - 5 | 1 | 13 | 73 | 14 |
| | | | 5 - 10 | 2 | 18 | 79 | 3 |
| | | | 10 - 15 | 3 | 23 | 72.5 | 4.5 |
| | 2 | B | 0 - 5 | 4 | 20.3 | 76.9 | 2.8 |
| | | | 5 - 10 | 5 | 14.5 | 76.8 | 8.7 |
| | | | 10 - 15 | 6 | 24 | 72 | 4 |
| | | | 15 - 20 | 7 | 23.5 | 73 | 3.5 |
| | 3 | C | 0 - 5 | 8 | 22.4 | 75.9 | 1.7 |
| | | | 5 - 10 | 9 | 20 | 78.7 | 1.3 |
| | | | 10 - 15 | 10 | 22 | 77 | 1 |
| | | | 15 - 20 | 11 | 23.7 | 75 | 1.3 |
| | 4 | D | 0 - 5 | 12 | 18.8 | 78.2 | 3 |
| | | | 5 - 10 | 13 | 20.4 | 76.6 | 3 |
| | | | 10 - 15 | 14 | 21 | 76 | 3 |
| | | | 15 - 20 | 15 | 21.2 | 75.6 | 3.2 |
| | 6 | E | 0 - 5 | 16 | 19.3 | 78 | 2.7 |
| | | | 5 - 10 | 17 | 20.6 | 77.6 | 1.8 |
| | | | 10 - 15 | 18 | 22 | 77.2 | 0.8 |
| | | | 15 - 20 | 19 | 21.6 | 76.4 | 2 |
| | | | 20 - 25 | 20 | 22.5 | 76 | 1.5 |
| | | | 25 - 30 | 21 | 20.8 | 78 | 1.2 |
| | 8 | F | 0 - 5 | 22 | 20.3 | 79.2 | 0.5 |
| | | | 5 - 10 | 23 | 20.2 | 78.3 | 1.5 |
| | | | 10 - 15 | 24 | 20 | 79 | 1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | 15 - 20 | 25 | 20.4 | 78.5 | 1.1 |
| | | | 20 - 25 | 26 | 21 | 78 | 1 |
| | | | 25 - 30 | 27 | 21.5 | 77.8 | 0.7 |
| | 10 | G | 0 - 5 | 28 | 21.9 | 77.5 | 0.6 |
| | | | 5 - 10 | 29 | 19.7 | 79.5 | 0.8 |
| | | | 10 - 15 | 30 | 24.9 | 74.9 | 0.2 |
| | | | 15 - 20 | 31 | 20.9 | 78.1 | 1 |
| | | | 20 - 25 | 32 | 22 | 77.2 | 0.8 |
| | | | 25 - 30 | 33 | 21.5 | 78.3 | 0.2 |
| | | | 30 - 35 | 34 | 21 | 78.3 | 0.7 |
| Ban Klong Tamru | 4 | A | 0 - 5 | 35 | 8.2 | 38.3 | 53.5 |
| | 6 | B | 0 - 5 | 36 | 3.9 | 15 | 81.1 |
| | 8 | C | 0 - 3 | 37 | 8.7 | 45.3 | 46 |
| | 10 | D | 0 - 2.5 | 38 | 8.7 | 45.3 | 46 |
| | | | 2.5 - 5 | 39 | 16.8 | 72 | 11.2 |
| | | | 5 - 7 | 40 | 18.3 | 69 | 12.7 |
| Ban Khok Kam | 2 | A | 0 - 2 | 41 | 19.2 | 79 | 1.8 |
| | | | 2 - 6 | 42 | 23.9 | 74.4 | 1.7 |
| | | | 6 - 11 | 43 | 23.5 | 74 | 2.5 |
| | | | 11 - 16 | 44 | 23.9 | 75.7 | 0.4 |
| | 4 | B | 0 - 5 | 45 | 21.5 | 76.7 | 1.8 |
| | | | 5 - 10 | 46 | 21.6 | 76.2 | 2.2 |
| | | | 10 - 15 | 47 | 27 | 71.2 | 1.8 |
| | 6 | C | 0 - 5 | 48 | 19.7 | 75.4 | 4.9 |
| | 8 | D | 0 - 5 | 49 | 18.9 | 76.1 | 5 |
| | | | 5 - 10 | 50 | 20.2 | 76.3 | 3.5 |
| | | | 10 - 15 | 51 | 27 | 72.4 | 0.6 |
| | 10 | E | 0 - 5 | 52 | 13.7 | 79.6 | 6.7 |
| | | | 5 - 10 | 53 | 14 | 71.9 | 14.1 |

**Figure 48** Sediment texture classification of 34 samples at Ban Khun Samut Chin survey line.




(Soil Textural Triangle: Source: U.S.D.A.)

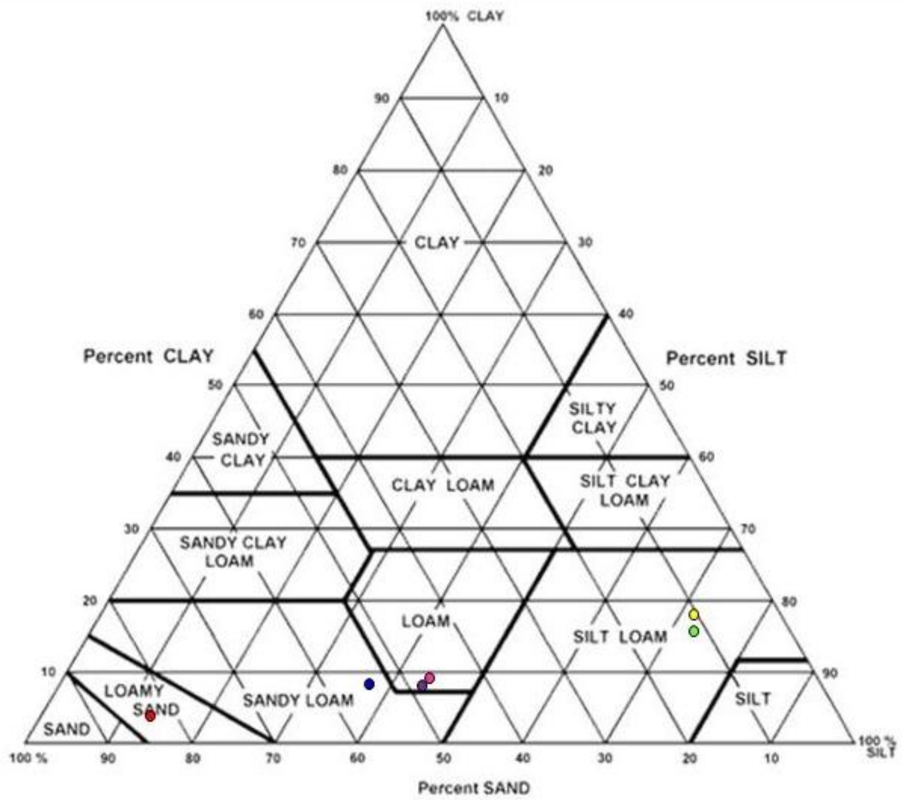
| Sample No. | Symbol | Sample No. | Symbol |
|---|---|---|---|
| 1 | ● | 18 | ▲ |
| 2 | ● | 19 | ▲ |
| 3 | ○ | 20 | △ |
| 4 | ● | 21 | ▲ |
| 5 | ○ | 22 | △ |
| 6 | ○ | 23 | △ |
| 7 | ○ | 24 | △ |
| 8 | ● | 25 | △ |
| 9 | ● | 26 | ▲ |
| 10 | ● | 27 | ▲ |
| 11 | ● | 28 | ▲ |
| 12 | ● | 29 | ▲ |
| 13 | ● | 30 | ▲ |
| 14 | ● | 31 | ▲ |
| 15 | ● | 32 | ▲ |
| 16 | ● | 33 | ▲ |
| 17 | ○ | 34 | △ |

Clay + Silt + Sand

= 100 %

Texture = Silt Loam

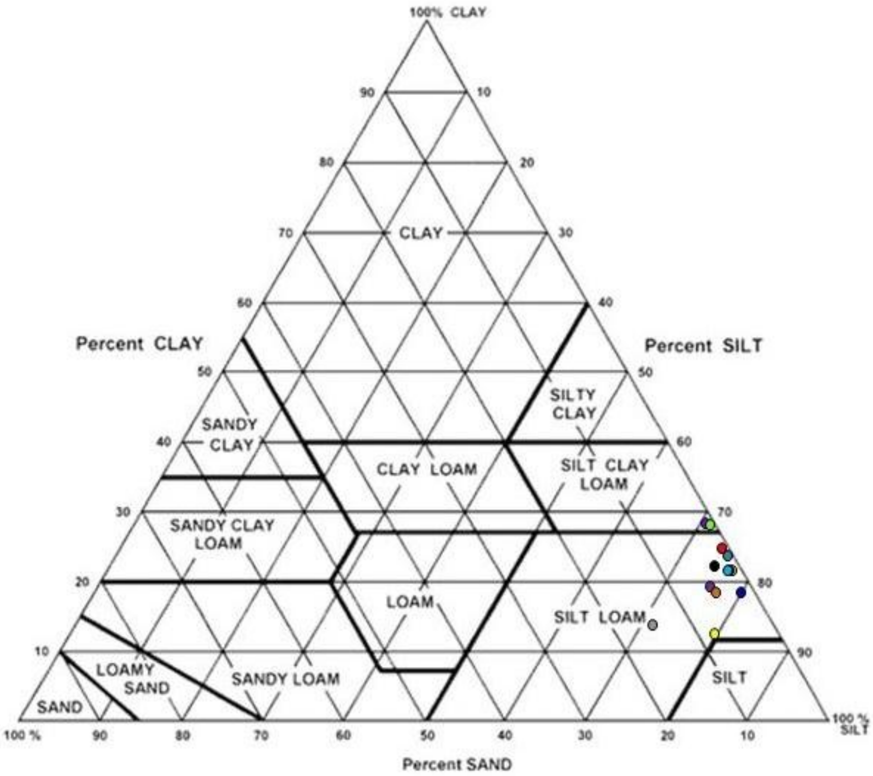
**Figure 49** Sediment texture classification of 6 samples at Ban Klong Tamru survey line.




(Soil Textural Triangle: Source: U.S.D.A.)

| Sample No. | Symbol | Texture |
|---|---|---|
| 35 | ● | Sandy Loam |
| 36 | ● | Loamy Sand |
| 37 | ● | Loam |
| 38 | ● | Loam |
| 39 | ○ | Silt Loam |
| 40 | ○ | Silt Loam |

**Figure 50** Sediment texture classification of 13 samples at Ban Khok Kam survey line.




(Soil Textural Triangle: Source: U.S.D.A.)

| Sample No. | Symbol | Texture | Sample No. | Symbol | Texture |
|---|---|---|---|---|---|
| 41 | ● | Silt Loam | 48 | ● | Silt Loam |
| 42 | ● | Silt Loam | 49 | ● | Silt Loam |
| 43 | ● | Silt Loam | 50 | ● | Silt Loam |
| 44 | ● | Silt Loam | 51 | ● | Silty Clay Loam |
| 45 | ● | Silt Loam | 52 | ● | Silt Loam |
| 46 | ● | Silt Loam | 53 | ● | Silt Loam |
| 47 | ● | Silty Clay Loam | | | |

# APPENDIX E

# CS-137 CONCENTRATIONS

**Table 16** Cs-137 concentration (Bq/g) of each sample.

| Survey Line | Distance (km) Offshore | Layer (cm) | Sample No. | Cs-137 (Bq/g) |
|---|---|---|---|---|
| Ban Khun Samut Chin | 1 | 0 – 5 | 1 | LLD |
| | | 5 – 10 | 2 | 0.00074 |
| | 2 | 0 – 5 | 3 | 0.0011 |
| | | 5 – 10 | 4 | 0.00057 |
| | 3 | 0 – 5 | 5 | 0.0023 |
| | | 5 – 10 | 6 | 0.0009 |
| | 4 | 0 – 5 | 7 | 0.003 |
| | | 5 – 10 | 8 | 0.0019 |
| | 6 | 0 – 5 | 9 | 0.0039 |
| | | 5 – 10 | 10 | 0.0014 |
| | 8 | 0 – 5 | 11 | 0.0025 |
| | | 5 – 10 | 12 | 0.0023 |
| | 10 | 0 – 5 | 13 | 0.0023 |
| | | 5 – 10 | 14 | 0.002 |
| Ban Klong Tamru | 4 | 0 – 5 | 15 | LLD |
| | 6 | 0 – 5 | 16 | LLD |
| | 8 | 0 – 3 | 17 | 0.00051 |
| | 10 | 0 – 2.5 | 18 | 0.0008 |
| | | 2.5 – 5 | 19 | 0.0013 |
| Ban Khok Kam | 2 | 0 – 2 | 20 | 0.0008 |
| | | 2 – 6 | 21 | 0.0011 |
| | 4 | 0 – 5 | 22 | 0.0026 |
| | | 5 – 10 | 23 | 0.0015 |
| | 6 | 0 – 5 | 24 | 0.0022 |
| | 8 | 0 – 5 | 25 | 0.003 |

| | | | | |
|---|---|---|---|---|
| | | 5 – 10 | 26 | 0.0034 |
| | 10 | 0 – 5 | 27 | 0.0019 |
| | | 5 – 10 | 28 | 0.0014 |

LLD = Lower Limit of Detection (Values are below background.)

# VITA

Ms. Rujiporn Suthisanonth was born on December 10, 1988 in Bangkok, Thailand. She got the Bachelor Degree in Biotechnology from Thammasat University, Thailand in 2011. After graduation, she continued her study in Master Degree program in Earth Sciences at Chulalongkorn University, Thailand.