ธรณีสัณฐานวิทยาของธารน้ำในอดีตและปัจจุบันของระบบแม่น้ำโค้งตวัดจากพื้นที่ต้นน้ำของแม่น้ำมูล จังหวัดนครราชสีมา

นางสาวปาริสา นิ่มเนตร

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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ANCIENT AND MODERN FLUVIAL GEOMORPHOLOGY OF MEANDERING SYSTEM FROM UPSTREAM AREA OF THE MUN RIVER, CHANGWAT NAKHON RATCHASIMA

Miss Parisa Nimnate

A Dissertation Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy Program in Geology
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Field of Study	Geology
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ปาริสา นิ่มเนตร : ธรณีสัณฐานวิทยาของธารน้ำในอดีตและปัจจุบันของระบบแม่น้ำโค้งตวัดจากพื้นที่ต้นน้ำของแม่น้ำมูล จังหวัดนครราชสีมา (ANCIENT AND MODERN FLUVIAL GEOMORPHOLOGY OF MEANDERING SYSTEM FROM UPSTREAM AREA OF THE MUN RIVER, CHANGWAT NAKHON RATCHASIMA) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ศ. ดร. มนตรี ชูวงษ์, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ผศ. ดร. ฐานบ ธิติมากร, 130 หน้า.

บริเวณขอบที่ราบสูงโคราชด้านตะวันตกเฉียงใต้ ต้นน้ำของแม่น้ำมูลไหลผ่านหินตะกอนเนื้อเม็ดทำให้ตะกอนทรายจำนวนมากได้ถูกพัดพาโดยแม่น้ำมูลสู่ปลายน้ำ เมื่อมีการก่อสร้างเขื่อนมูลบนในปี ค.ศ.1986 (พ.ศ.2529) คาดว่าจะส่งผลกระทบไม่มากก็น้อยต่อระบบทางน้ำ ดังนั้นวิทยานิพนธ์นี้มีจุดประสงค์เพื่อวิเคราะห์ธรณีสัณฐานที่เปลี่ยนไปหลังจากการสร้างเขื่อน และเพื่อจำแนกชุดลักษณ์ตะกอนจากการสำรวจทางธรณีวิทยาและธรณีฟิสิกส์ระดับตื้น การวิเคราะห์ตัวแปรทางธรณีสัณฐานโดยใช้ข้อมูลจากภาพถ่ายทางอากาศและภาพถ่ายดาวเทียมปี ค.ศ. 1974 1986 และ 2011 ค่าดัชนีความโค้ง ความกว้างของแม่น้ำ และค่ารัศมีความโค้งจะช่วยบอกพฤติกรรมของแม่น้ำได้ว่าจะมีการลัดของทางน้ำ การกัดเซาะตลิ่งหรือไม่ จากคำนวณและเปรียบเทียบค่าตัวแปรเหล่านี้พบว่าทางน้ำเก่าขนาดกลางและขนาดเล็กที่พบบริเวณที่ราบน้ำท่วมถึง มีความกว้างเฉลี่ย 35 เมตรและ 16 เมตร ตามลำดับ ซึ่งแม่น้ำมูลปัจจุบันมีความกว้างเฉลี่ย 13 เมตร ค่าดัชนีความโค้งแม่น้ำในอดีตและปัจจุบัน อยู่ในช่วงของแม่น้ำโค้งตวัด (1.5 และ 2.5) จากความสัมพันธ์ของค่าดัชนีความโค้ง ความกว้างของแม่น้ำและอัตราการเคลื่อนตัวของแม่น้ำพบว่าแม่น้ำมูลนบริเวณที่พื้นที่ศึกษามีความคงตัวตั้งแต่อดีตถึงปัจจุบัน โดยมีอัตราการเคลื่อนที่กวัดแกว่งทางด้านข้าง 0.71 ถึง 2.64 เมตรต่อปี ผลการสำรวจทางธรณีฟิสิกส์ระดับตื้นมีการวิเคราะห์ควบคู่กับข้อมูลเจาะสำรวจตะกอนใกล้บริเวณแนวสำรวจ ผลการสำรวจGPRพบลักษณะของการสะท้อนกลับของคลื่นเรดาห์ 4 รูปแบบ ได้แก่ reflection free, shingled, inclined และ hummocky ซึ่งทำให้ทราบโครงสร้างของชั้นตะกอนใต้ดิน นอกจากนี้การสำรวจความต้านทานไฟฟ้าบริเวณใต้ดินทำให้สามารถทราบชนิดของการสะสมตัวของตะกอนที่มีความแตกต่างกันและลักษณะรูปร่างของแม่น้ำเก่าอีกด้วย

ภาควิชา	ธรณีวิทยา	ลายมือชื่อนิสิต	....
สาขาวิชา	ธรณีวิทยา	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
ปีการศึกษา	2560	ลายมือชื่อ อ.ที่ปรึกษาร่วม	....

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PARISA NIMNATE: ANCIENT AND MODERN FLUVIAL GEOMORPHOLOGY OF MEANDERING SYSTEM FROM UPSTREAM AREA OF THE MUN RIVER, CHANGWAT NAKHON RATCHASIMA. ADVISOR: PROF. MONTRI CHOOWONG, Ph.D., CO-ADVISOR: ASST. PROF. THANOP THITIMAKORN, Ph.D., 130 pp.

At the southwestern rim of the Khorat Plateau, the upstream part of the Mun River flows through clastic sedimentary rocks leading to a massive amount of sand was transported via the Mun River to downstream. The Mun Bon Dam was constructed in 1986, and it would be effect more or less on river system. Therefore, the aim of this thesis is to analyze the geomorphological changes before and after the Mun Bon Dam construction. Moreover, the sedimentary facies from geological and shallow geophysical surveys were characterized. The geomorphic parameters was analyzed from series of aerial–photo and satellite image which were taken in 1974, 1986, and 2011. The sinuosity, width and radius of curvature of the river channels were comprehend the channel stability and possibility of cut off or bank erosion process. Medium and Small sized paleo-channel were recognized and their average channel widths were 35 m and 16 m, whereas the Mun River is of 13 m. SI values of two paleo-channel belts are categorized as meandering river system. The channel stability indicated that the Mun River has low rate of erosion for long time with the migration rate of 0.71 to 2.64 m/yr. Shallow geophysical survey was verified with on-sited boreholes along survey lines. Four radar reflection patterns including reflection free, shingled, inclined and hummocky reflections were represented lateral accretion of point bar from GPR survey. Besides, subsurface lithology and channel geometry derived from the different of resistivity from Electrical Resistivity Tomography survey.

Department:	Geology	Student's Signature	....
Field of Study:	Geology	Advisor's Signature	....
Academic Year:	2017	Co-Advisor's Signature	....

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It is not easy to mention all persons who have contributed to my research. I, personally, have already expressed my gratitude to everyone that has direct and indirect assistance with this research. Finally, I have to thanks my parents for their moral support and encouragement and my close friend who invariably help me directly and indirectly. Financially, I would like to thank the Human Resources Development in Science Project (Science Achievement Scholarship of Thailand, SAST) for financial support during I had been being a master and doctoral students.

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CHAPTER I
Introduction

The main points in this chapter consist of general background, background of study area, and objectives. The detail of rationale of thesis shows in general background. The background of study area will explain about the Mun River and Geology. Finally is objectives.

1.1 General background

Fluvial geomorphology researches were emphasized on how to describe the variety of fluvial geomorphology in different environments. River management which is more scientific work taken place in the 1930s and 1940s, such as the experiment of the Mississippi meanders (Friedkin, 1945). Moreover, meanders developing process and migrate to downstream was determined (Hooke, 2007). Nowadays, surface and subsurface conditions of meander development are challenging research on how to measure the long-term development. The channel stability from seventeen rivers in Sweden has been carried out by using radius of curvature (Rc) (Williams, 1986), Red and Mississippi River (Thorne, 1991) and Beatton River (Neal, 2004). River process has also been researched about the river channels change due to human interference (Chaimanee et al., 2006, Hooke, 1995, 2013). Human activities can sometimes induce channel change in river morphology and their process more significantly than floods, droughts and landslides which is the natural process (Ashraf and Liu, 2013, Surian and Rinaldi, 2003).

Aerial photography and remotely sensed data interpretation has widely applied for detecting and mapping landform, measuring temporal changes in fluvial landforms (Kondolf et al., 2005). For understanding of meander change, the historic maps are the useful source to provide much information on morphologic changes of large river. However, the limitation in accuracy of production during rectification process can be occurring. Moreover, aerial photographs, satellite images and cross-sectional surveys contribute a wealth of information to geomorphologic research of fluvial geomorphology (Ashraf and Liu, 2013, Chaimanee et al., 2006). The relationship between morphologic changes and their causes can explain past river dynamics and infer possible future trends. The changing can be natural or, quite often, related to human interventions (Ziliani and Surian, 2015), so the relict fluvial geomorphology such as oxbow lake and meandered scar are the evidence from river channel flowing in the past. As for geomorphic planform parameters, the data on channel sinuosity (SI) , meander wavelength (W), and bend radius of curvature (Rc) have agreed with the channel stability (relationships between Rc-values, W, SI and migration rate / year) which predicted by Langbein and Leopold (Langbein and Leopold, 1966, Williams, 1986), and it is useful for study the fluvial process.

The geophysical survey is the useful tool for understanding the subsurface depositions. Especially, the location of the main geomorphic units (such as paleo-channels (meandered scar), point bar and floodplain) were examine the detail about lithological data and sedimentary structures by using the shallow geophysical survey for study the fluvial process in the pass. Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR) geophysical techniques have been widely used in the past for describing the Quaternary deposit lithological and sedimentological characterization (Baines, 2002, Pellicer and Gibson, 2011, Wisen, 2005). In the past two decades, ERT and GPR have been paid to more attention and proved as one of higher resolution geophysical techniques. ERT has been widely applied in environmental and engineering geophysical survey to obtain 2D and 3D high resolution images of the subsurface geology (Rey et al., 2013). On the other hand, GPR detects dielectric constant properties of sediment layers, therefore, the data will show discontinuities in the shallow subsurface generally less than 20 m depth. Moreover, the ERT is a particular useful survey method in clayey ground, where GPR is less effective. ERT technique commonly shows the variations of large scale sedimentary deposit (Shaaban and Shaaban, 2001). These two geophysical methods are good combination for sedimentological investigations, particularly in place where variations in subsurface lithological conditions occur.

GPR was first applied and used in civil engineering purpose, glaciology and archaeological applications, but then it becomes the useful method for geological and sedimentological studies (Smith and Jol, 1995). Since the mid-1990s, GPR has been used to reconstruct the past depositional environments and nature of sedimentary processes in a variety of environmental settings (Neal, 2004). In general, GPR survey applies the principle of generation, propagation, reflection and reception of high frequency electromagnetic pulses. Signal responses can be directly related to change in relative porosity, material composition and moisture content (Cassidy et al., 2009). GPR method can also help to identify transitional boundaries in subsurface layers that can be difficult to detect by using other geophysical methods. It is a non-destructive, high-resolution method for detecting and mapping subsurface layers, which can be recognized by differing radar reflectors produced (Davis and Annan, 1989). However, geophysical survey interpreting in accordance with sedimentary data from boreholes is also common and good combination to describe the fluvial geomorphology from subsurface. The sediment cores were drilled along shallow geophysical survey line. After that the sediment from each layer was selected for grain size analysis for identifying sediment type.

Recently, works related to river morphology in northeast Thailand have been focused on sediment and fossil analyses found along the Mun River in the Khorat basin. None of research regarding the analysis in geomorphic parameters has been done before. Moreover, the past fluvial process that analyzed from subsurface fluvial succession from paleo-channel doesn't reported. Therefore, this research is the first of its kind in analyzing geomorphology of the Mun River, a largest meandering river on the Khorat Plateau (Figure 1). Particular focus is paid on geomorphic planform parameters for characterizing and describing the recent Mun River and paleo-channels on the Mun River floodplain.

The Mun River flows from Mun Bon Dam locating at Khon Buri District (Figure 2). Some parts of the Mun River have more than one channels separated from main channel and rejoin again similar to those found from the anastomosing Kizilirmak River, Turkey (Ozturk and Sesli, 2015). We set up the purpose to ascertain the temporal analysis of the upstream part of the river that flows from the south (Sankamphaeng Mountain Range) to the north (near Nakhon Ratchasima downtown) and to explain the change of such geomorphologic parameters over times from 1974 to 2015. We aim to understand the difference between recent and past river landform development at similar geological setting. We also hypothesize that the Mun Bon Dam construction may alter the fluvial geomorphology. Understanding such an alteration can be made possible by using the geomorphic planform parameters including channel width, channel length, down valley length and lateral migration rate.

The subsurface geophysical investigation aimed to understand the deposition of sand-dominated fluvial system on the Khorat Plateau. The advantages of two shallow geophysical methods (ERT and GPR) will be discussed. In this research, paleo-channels, floodplains and recent point bars are targets for both shallow geophysical investigations. Moreover, sediment cores from boreholes were collected to compare and verify the geophysical interpretation. The upstream part of the Mun River was selected for this investigation because of less human activity affects. The objectives of the ERT and GPR survey were to detect lateral and vertical variations of shallow unconsolidated fluvial deposits from point bar, floodplain and paleo- channels. Moreover, Grain size analysis from each borehole is expected to provide key for the interpretation of apparent resistivity from inversion model for cross section to make ERT lithological classes in correspond with sediment grain size. The other purpose is to determine the geomorphlologic change after the Mun Bon Dam construction from 1974 to 2015.

1.2 Background of the study area

1.2.1 The Mun River

The Mun River is the longest one flowing on the Khorat Plateau mostly in west to east direction. It is the right bank tributary of the Mekong River (Colombera et al., 2013), situated in the northeastern part of Thailand. It lies between latitudes 14° and 16°, and longitudes 101°30 and 105°30 (Akter and Babel, 2012) (Figure 1.1). The river begins in the Khao Yai National Park area of the Sankamphaeng Range, near Nakhon Ratchasima in northeast Thailand. It flows east through the Khorat Plateau in southern Isan (Buriram, Surin, and Sisaket Provinces) for 750 kilometres, until it joins the Mekong at Khong Chiam in Ubon Ratchathani. The Mun River's main tributary is the Chi River, which joins it in the Kanthararom District of Sisaket Province. It carries approximately 26 cubic kilometres (6.2 cu mi) of water per year, and the aim of this dam is irrigation purpose.

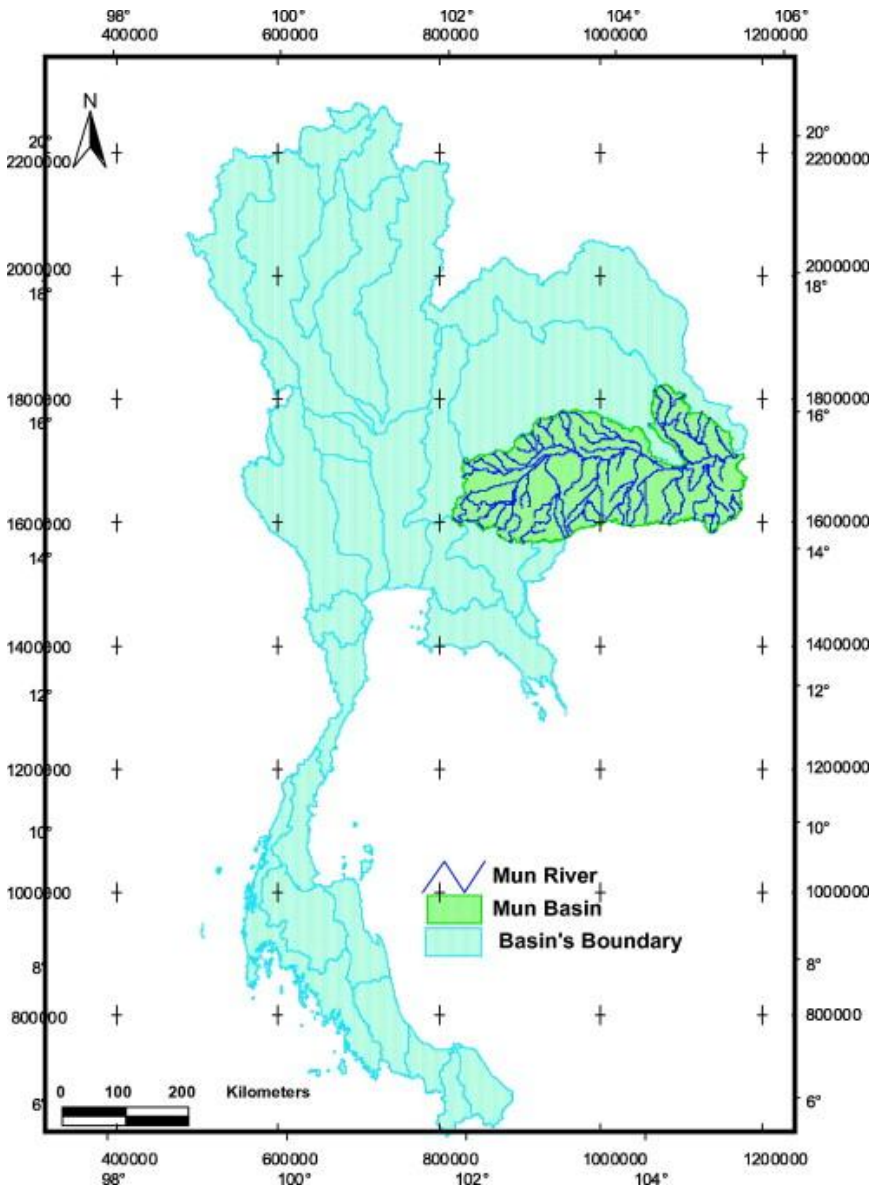

Figure 1 This figure shows the Mun River Basin and Mun River distributaries boundary from the origin and the end which joins the Mekong River (Akter and Babel, 2012).

1.2.2 Geology of study area

The Khorat Plateau is the largest clastic sedimentary rock plateaus in Southeast Asia. The Khorat plateau is elevated from a hundred meter above the present mean sea level. It is the main part of Indochina continent that was lastly uplifted by Himalayan orogeny. The plateau is mainly located in Thailand and partially extending to Laos PDR and Cambodia. In terms of geological structures, the plateau consists of two large synclinal basins. The southern basin has two main rivers; the Mun and the Chi Rivers. At the southwest rim cuesta of the Khorat Plateau, the Mun River is originated. The

Mun River scours into clastic rock basement providing a massive amount of sand transported via the river to form fluvial system on the low-lying plain downstream. Geomorphic trace of various sizes paleo-channels can be depicted from aerial photographs on the recent floodplains.

The Khorat Group consists of a thick sequence of red clays, siltstone, sandstone and conglomerates. It is stratigraphically subdivided into six formations from bottom to top: the Upper Nam Phong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, and Khok Kruat formations and the age is inferred to Jurassic and Cretaceous (Horiuchi et al., 2012, Meesook and Saengsrichan, 2011). The Khorat sand beds are overlain by unconsolidated Quaternary alluvial sediment (Dheeradilok, 1993). The location of study area and geologic map displays rock and unconsolidated sediments in Figure 2.

The Nam Phong Formation

The Nam Phong Formation is the basal unit of the Khorat Group. It consists of resistant, red-brown, micaceous sandstones, conglomerates, siltstone and mudstone of mainly fluvial origin. The sandstones are medium to very fine-grained with calcareous cement. The conglomerates contain pebbles of quartz, brown and gray chert, and reddish-brown siltstone. Cross-bedding and plane-bed stratification are common in the sandstones and conglomerates. The sandstones and conglomerates make up approximately 30% of the formation.

The Phu Kradung Formation

The Phu Kradung Formation at its type locality in Loei Province measures 1 001 m in thickness. The lower half of the section consists mostly of soft, micaceous, reddish brown and grayish-red siltstone with rare grayish-red to greenish-gray calcareous conglomerate beds. Interbedded calcareous micaceous siltstone and sandstone characterize the upper half of the formation.

The Phra Wihan Formation

The Phra Wihan Formation cannot be clearly differentiated on seismic profiles. It consists predominantly of white, yellowish, light brown sandstones, less abundant grayish-red siltstone and rare green or dark red clay. The sandstone is medium- to coarse-grained, consisting of clean quartz sand grains with a few scattered grains of gray to black chert.

The Sao Khua Formation

The Sao Khua Formation is almost transparent on seismic profiles, with discontinuous low amplitude markers. It consists of an alternation of grayish-reddish brown siltstone and clay and pale red to yellowish-gray, fine-grained to medium-grained sandstone. Rare pale red to light gray conglomerates, containing carbonate pebbles are also characteristic of this Formation.

The Phu Phan Formation

The Phu Phan Formation is represented on seismic profiles by two parallel, relatively continuous markers. It consists of fine- to coarse-grained and conglomeratic sandstone containing rounded pebbles of quartz and chert. The sandstones are often stacked into 15 to 40 m thick units. They are yellowish-gray to pale orange, pinkish gray and pale red. Trough and planar cross-bedding are normally observed. The lower contact with the underlying Sao Khua Formation is very sharp and erosive, characterized by sand-supported caliche pebble conglomerates; red silty claystone and caliche are occasionally present.

The Khok Kruat Formation

The Khok Kruat Formation is characterized on seismic profile by a sub-transparent pattern with discontinuous markers of moderate energy. It rests conformably on the Phu Phan Formation and forms the uppermost unit of the Khorat Group. The Khok Kruat Formation consists of siltstone and sandstone with some caliche pebble conglomerates. The sandstones are pale red to grayish-red and reddish brown in color, fine- to medium-grained, thick bedded to flaggy, and cross-bedded. They are generally micaceous or arkoses, and often contain clay rip-up casts. The upper part of the Formation contains a thin gypsum bed.

The Quaternary deposits of the Khorat Plateau are present in two basins; the Khorat and Sakon Nakhon Basins. Terrace and inferred aeolian deposit are dominant Quaternary deposit in both basins. The Meander belt of the Mun River is characterized by the localized presence of relict gravel beds from Mesozoic sandstone basement (Dheeradilok, 1993, Meesook and Saengsrichan, 2011). The quaternary sediment consists of Quaternary terrace and Quaternary Alluvial deposits. Quaternary terrace (Q_t) sediments are colluvial gravel, sand and silt; local laterite and lateritic soil. The Quaternary alluvial (Q_a) sediments are associated with alluvial gravel, sand, silt and clay of floodplain and swamp deposits. In the study area found only the Quaternary alluvial along the Mun River.

1.3 Objectives

This research will be focused on geomorphic analysis of the upstream part of the Mun River, which is located from the Mun Bon Dam northwardly extending downstream to parts of Amphoe Khon Buri and Amphoe Muang in Changwat Nakhon Ratchasima, northeastern Thailand. In general, the Mun River in this area shows meandering river patterns. Lateral changes of the meandered belts will be examined from the interpretation of aerial photographs and satellite image. On the other hand, the vertical changes of channel filled and incised stream will be investigated in the field. In addition, lateral and vertical changes of sedimentary sequences along the Mun River will be carried out by shallow geophysical survey and sedimentological investigation. Therefore, the main objectives of the thesis research are set up as follows.

1. To analyze the geomorphological changes before and after the Mun Bon Dam construction from the upstream part of the Mun River meandering patterns from different periods of times from 1954 to 2014.
2. To characterize sedimentary facies from geological and shallow geophysical surveys (e.g., sediment core, ground penetrating radar, ERT survey) from the upstream part of the Mun River system.

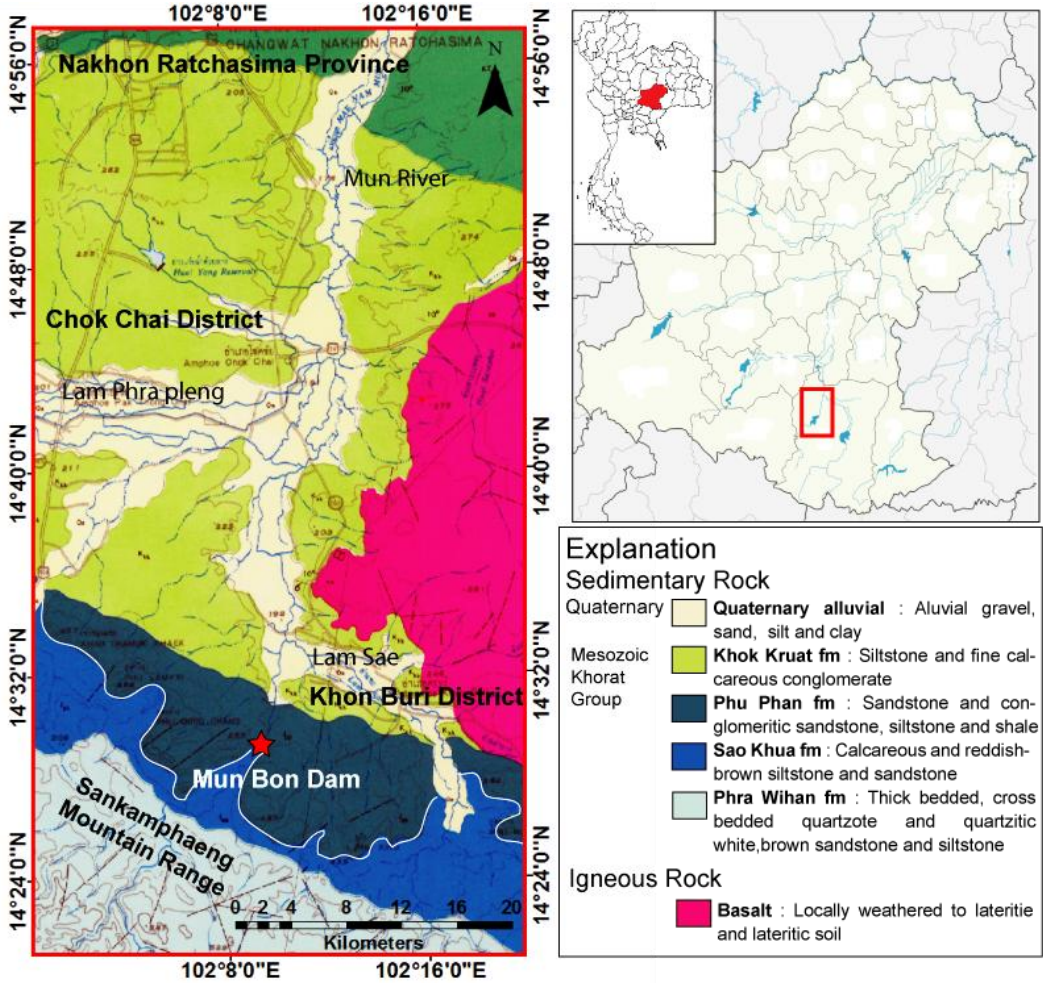

Figure 2 Index map of northeast Thailand (upper right figure) showing the location of the study area (red block) overlying on geologic map scale 1:250,000 (left figure). The geologic map displays the distribution of rock units, unconsolidated Quaternary sediments and location of the Mun Bon Dam (red star) (Nimnate et al., 2017).

CHAPTER II
Theoretical and empirical background

This chapter presents theory and empirical background about fluvial geomorphology, geomorphic planform parameters and shallow geophysical survey in fluvial sediment. The fluvial geomorphology especially the meandering river system, fluvial landform and the sediment succession were review. The geomorphic parameters includes the sinuosity index (SI), Radius of curvature (Rc) and channel migration. The last point, Ground penetrating radar (GPR) and Electrical Resistivity Tomography (ERT) were introduced.

2.1 Fluvial geomorphology

Fluvial geomorphology is the study of the form and function of streams and the interaction between streams and the landscape around them. 'Fluvial' refers to the processes associated with running waters, 'geo' refers to earth and 'morphology' refers to channel shape. Stream morphology is dynamic and constantly changing in both space and time. A stable stream channel is in a state of equilibrium and responds physically to the stream flow and sediment it receives from upstream (Church, 1992).

Rivers and streams are not only conduits of water, but also of sediment. The water, as it flows over the channel bed, is able to mobilize sediment and transport it downstream, either as bed load, suspended load or dissolved load. The rate of sediment transport depends on the availability of sediment itself and on the river's discharge (Church and Zimmermann, 2007).

2.1.1 The meandering fluvial system

This part will explain about the meandering river channels system. The name of meandering river was derived from remarkable loops river in Anatolia. The term meandering has become a term of classification for a certain type of pattern. The various types of meander indicated different underlying causes. Meanders are subdivided into free or river meanders which develop in their own alluvial, and incised meanders or meandering valleys.

The summary of factors influence stream profile (Reynolds et al., 2012).

- **Rock type**

As the river flows over different kind of rock, its ability to erode a channel is difference. The river type influences by the type of rock over which it flows. The river is easily eroded in unconsolidated sediment and rocks, such as shale, and it can create a smooth equilibrium like profile because they are no major obstacle. More resistant rocks are harder for erosion will tend to form steep slopes, with cliffs, waterfall, steep rapids and narrow canyons.

- **Tectonic**

Tectonic force can uplift or subsidence, the subsidence can flatten or steepen gradients, depending on where it occurs. Tectonic uplift generally causes rivers and streams to erode down into the landscape to the river base level.

- **Sea level**

Sea level is the ultimate base level for rivers. Changes in sea level will change the location of the shoreline and the elevation of base level. If the base level is lowered, such as by a drop in sea level, then the river will down cut to try to reach the new base level. If the base level rises, such as during a rise in sea level, the river will erode inland but deposit sediment along the coastline's new position, as the river tries to achieve its equilibrium profile.

- **Climate**

Rivers respond to changes in climate, such as an increase or decrease in rainfall or temperature. Under wet conditions, slopes will have more vegetation and so can hold soil, but increased discharge allows streams to carry sediment away, beveling the hills more than during dry periods.

As streams respond to change to a new state of equilibrium the stream undergoes by physical change through processes of degradation, widening and aggradation. The table 1 shows the process on the river environment, descriptions and the triggers of these processes.

Table 1 The stream physical change modified from (Church, 1992)

Process	**Description**	**Triggers**
Degradation	Lowering of streambed elevation through erosion and scour of bed material	• increased flow • decreased sediment supply • increased slope due to a reduction of channel sinuosity
Widening	Increase in stream channel width through erosion	• often follows channel degradation • increased flows within a degraded channel leads to erosion of both banks
Aggradation	Building-up of streambed elevation through sediment deposition	• decreased flow • increased sediment supply • decreased slope due to irregular meander migrations

Channel Types, Morphology, and Indicators of Disturbance

Channel type can be classified based on the type of material. Channel patterns classified on the basis of the caliber and volume of sediment supply (Church, 1992). The river patterns separate based on how the sediment supply was transported (Figure 3). Bed material supply and wash material supply, and a transitional phase (neither bed nor wash material dominates) are three patterns of materials. Bed material generally forms the coarser part of the sediment load a channel, and it is able to transport and constitutes the bed and lower banks of the stream. The wash material is the finer part of the sediment loads, and is generally transported long distances. These finer particles are deposited in the upper banks and on the floodplain. Generally, bed material consists of coarser sands, gravels, cobbles, and boulders while wash material consists of finer sands, silts, and clays. The flow energy of the particular channel determines whether sand-sized sediment is assigned to bed or wash material (Church and Zimmermann, 2007).

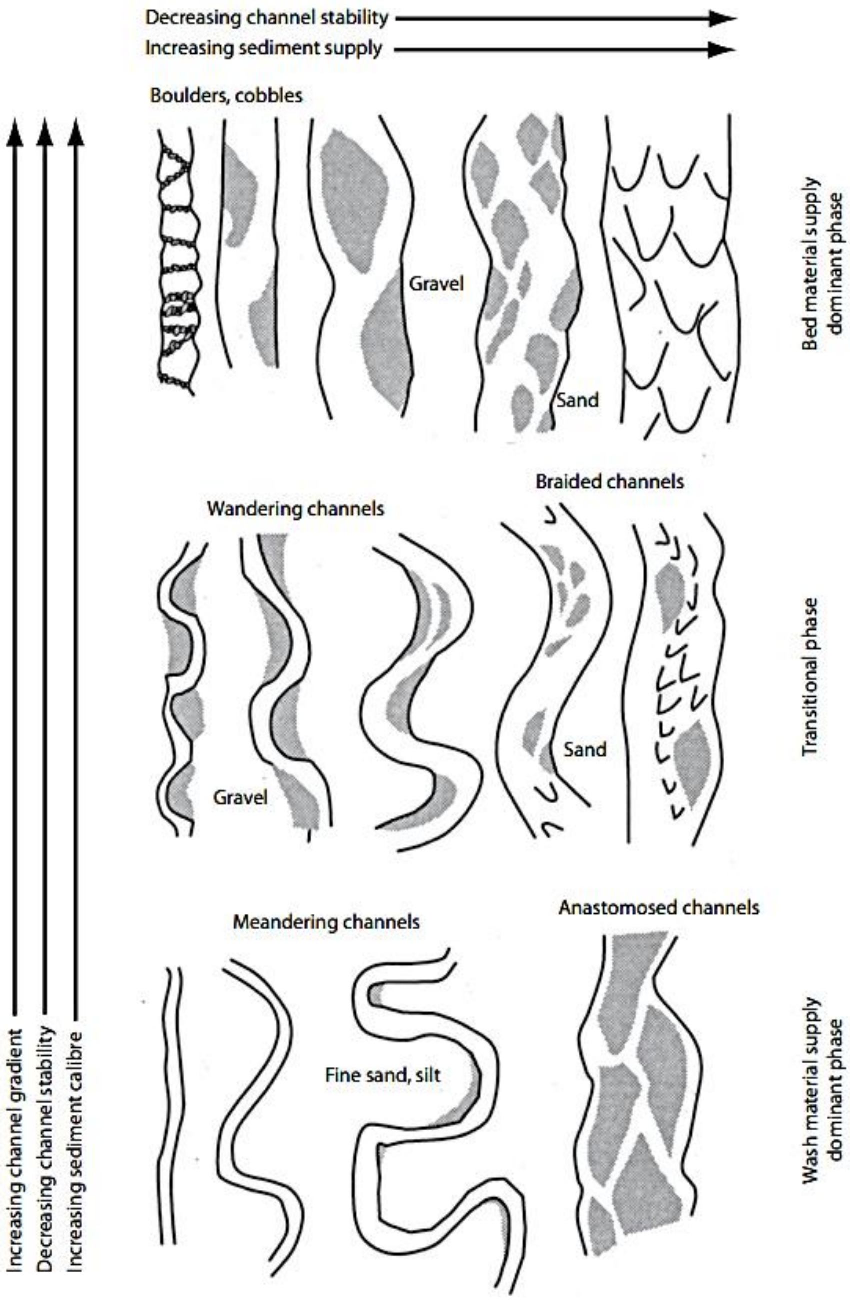

Figure 3 Channel forms are controlled by channel stability, sediment supply, sediment caliber and channel gradient (Church, 1992).

The movement of water applies force to a channel's bottom and sides and it is able to pick up and transport particles. The various size of sediment and their transportation shows in Figure 4. Water also transports material chemically dissolved in solution. Fine particle such as silt and clay can be carried by suspended in the moving water, event in a relatively slow current. Sand grains can roll along the bottom or carried down-current by bouncing along the streambed. It's called saltation process. Large cobbles and boulders generally move by rolling and sliding, but only during time high flow (Reynolds et al., 2012).

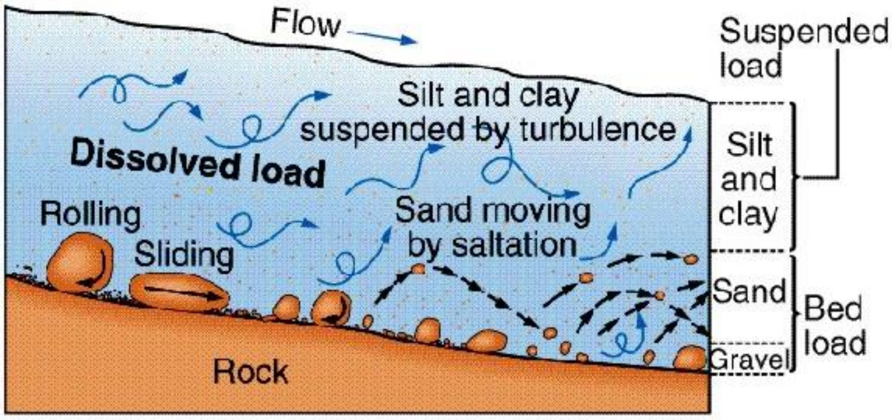

Figure 4 The various size of sediment and their transportation (contents of a stream bed) (http://www.personal.kent.edu/~sclement/dynamics/rivers/rivers.htm)

2.1.2 Meandering fluvial landform and sediment succession

Meandering of a stream is associated with low slope topography, high suspended load/bed load ratio, cohesive bank material, and relatively steady discharge. The sediments transported and deposited for this type of river usually occur on low-relief plains. The sediment sizes are mostly clay to sand size, but it can include fine gravels. The gentle landscape landforms reflect the interaction of river velocity and sediment size. Many rivers flow across plains that have gentle overall slopes. Sediments that deposited by rivers have been classified in several different manners. Most of geomorphologists distinguish these changing between vertical accretion and lateral accretion deposit. The meandering river landforms are classified as channel, point bar, crevasse splay, meander scars, oxbow Lakes, floodplain and terrace (Figure 5) (Reynolds et al., 2012).

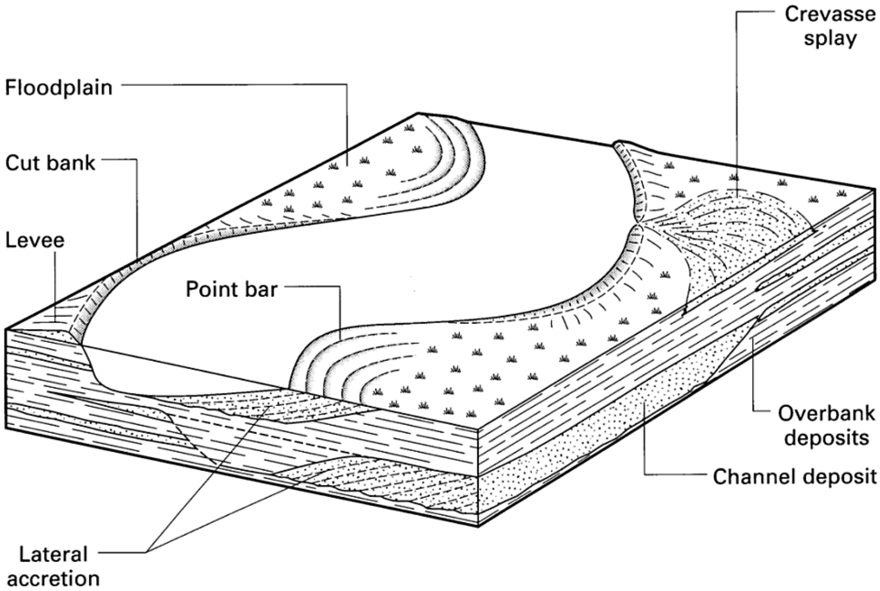

Figure 5 The meandering river landforms.
(http://www.seddepseq.co.uk/DEPOSITIONAL_ENV/Fluvial/Fluvial.htm)

1) Channel

This single-channel of meandering river characteristic is linked to the gentle downstream gradient of the river and its floodplain. The river begins to leave the mountains and spreads out across a broad floodplain. The characteristic of river flow in the meander channel, the area of the shallower of the channel the water velocity is lower on the inside of a bend, so the sediments deposit on the inside of the bend. On the other hand, the channel is deeper, and water flows faster on the outside of the bend. This factor causes the outside bend to be eroded into a steep river bank. In cross-section of channel, the path of the fastest current is called a helix, where rapid surface waters encounter the cut bank then curl across the bottom toward the point bar (Figure 6).

Sediments transported by a river cover a wide range of particle sizes. Silt and clay carried away much faster in suspension and deposited along their levee and bank. However, in the channel, the coarser sediments are gravels and pebbles, and sand (Surian and Rinaldi, 2003).

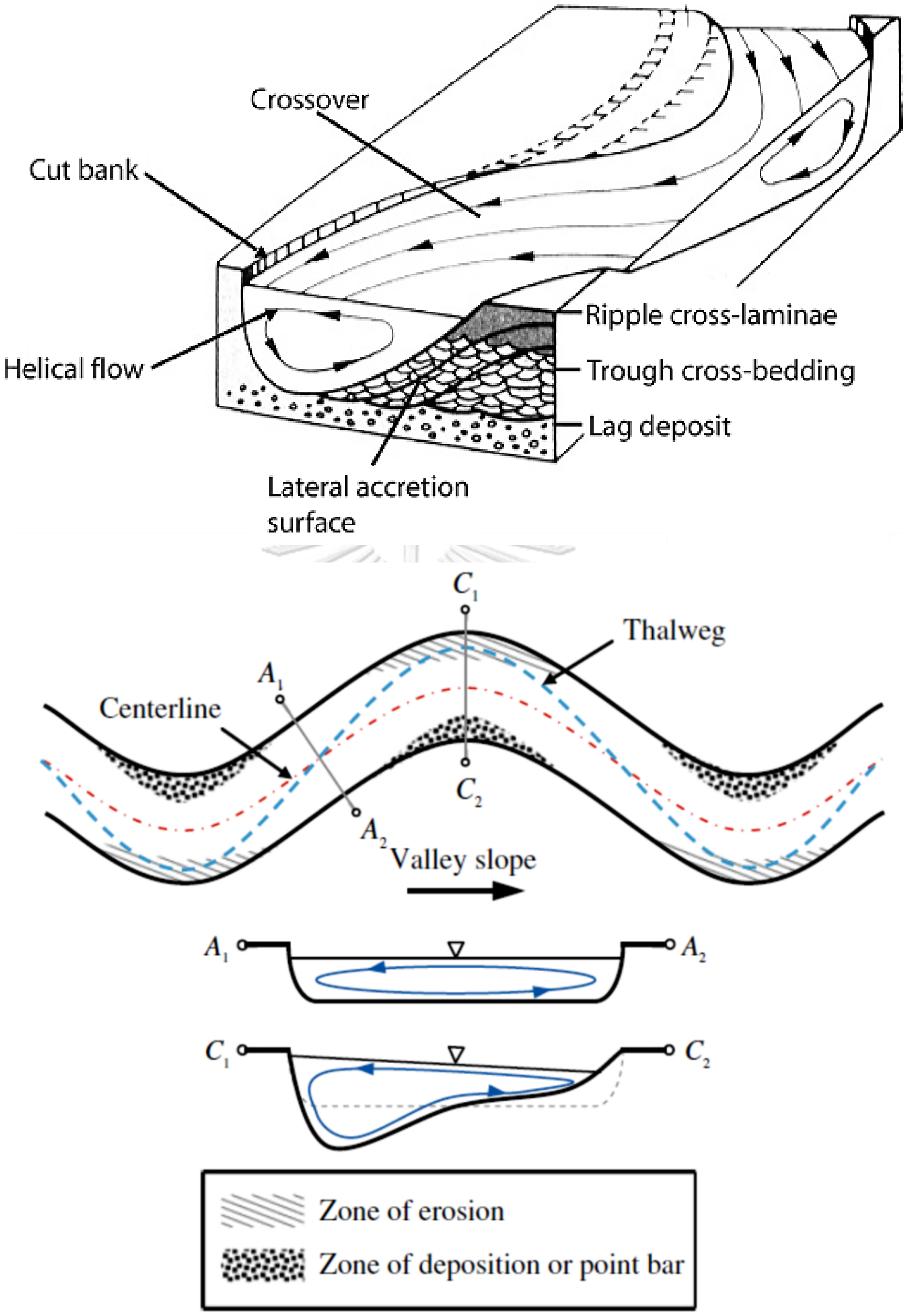

Figure 6 Picture showing zones of erosion and deposition in a meandering river. The water flow faster on the cut bank side where the erosion process occurs. The inner bank is slower river flow, so the sediment deposit as point bar (Dey, 2014).

2) Point bar

Point bars are the most obvious geomorphic feature of a meandering river; and point bars deposit is the major process of sedimentation in meandering river channel. Deposition on point bars results from lateral migration of meandering river by erosion and deposition processes.

Lithology and grain size of point bar deposits depend upon the grain size available. If a wide range of grain size is available, grain size decreases upward in a point bar sequence. In rivers carrying fine-grained material is fine sand layers near the bottom to muddy and clayey sediments near the top. Sometime in the lower part of the point bar sequence several channel lag layers may become in cooperated. Cross-bedding of current ripple origin are the major bedding types in the point bar deposits (Figure 7) (Surian and Rinaldi, 2003).

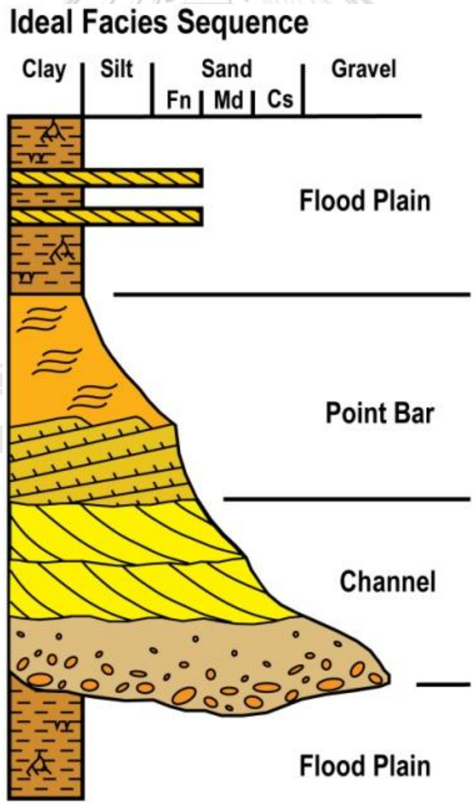

Figure 7 Point bar deposits on inner banks and typically accrete laterally, commonly resulting in lateral- accretion surfaces and downstream. (modified from http://csmres.jmu.edu/geollab/Fichter/SedRx/meanderriver.html)

3) Natural levee

Along the edge of many channel, natural levee are created by River (Reynolds et al., 2012). The levees gently slope from the river bank into floodplain. Natural levees are formed by deposition of sediment when flood waters of a stream overtop its banks. The velocity is reduced, causing deposition of much of suspended sediment near the channel. Coarser sediments deposit near the channel, and grain size decrease away from the channel. The maximum height of the natural levee indicates the water level reached during the highest floods (Surian and Rinaldi, 2003).

The levee sediments are finer grain material than point bar sediments. Sedimentary structures of levee deposit include small-ripple cross-bedding, climbing-ripple lamination, and parallel laminated mud layers (Figure 8). Thus, in a vertical sequence sandy and muddy layers are alternate each other. Surface features, e.g., desiccation cracks or raindrop imprints are commonly present on the muddy surface of levee deposit. Soil-forming processes that lead to mottling of the uppermost part of a mud layers, are rather active. Larger levee supports much plant growth. Therefore, much plant debris and organic matter is incorporated into levee sediments (Surian and Rinaldi, 2003).

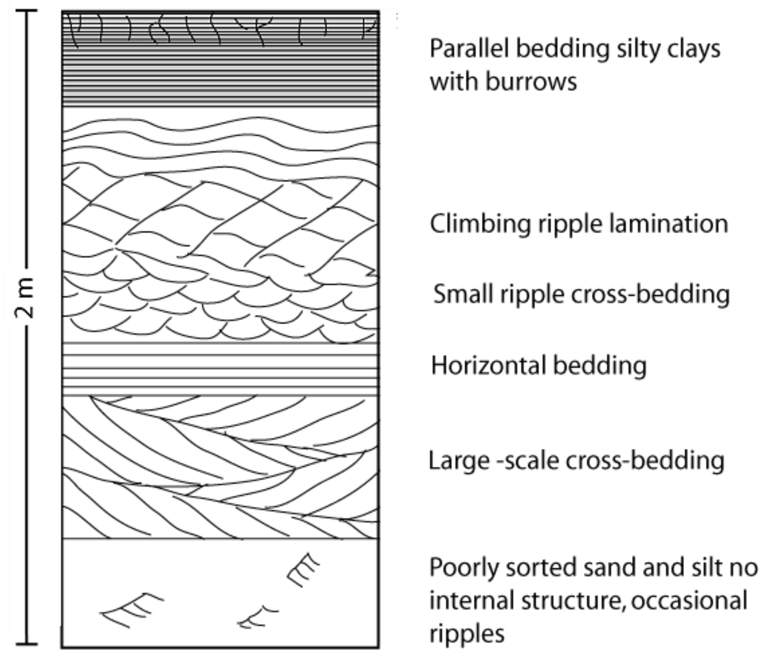

Figure 8 Sequence of Sedimentary structure of natural levee deposits of the Bhramaputra River modified from (Surian and Rinaldi, 2003)

4) Crevasse-Splay

During high flood, large quantities of flood water and sediment are diverted into an adjacent floodplain. Most over topping occurs on concave banks. The water cuts channels, and it was called crevasses. Crevasse extends across the levee in to the floodplain. Crevasse splay deposits are narrow to broad tongues of sediment, and the grain size is coarser than the natural levee deposit Sandy sequence is generally capped by muddy sediments. Scour and fill structure are commonly found (Surian and Rinaldi, 2003).

5) Meander Scar and Oxbow Lake (Channels–fill deposit)

Channel-fill deposits represent sedimentation in stream channels that have been abandoned by a stream because of cut-off processes or avulsions. The cut-off process is associated with the meandering streams and scours when the stream can shorten its course and thus locally increase its slope. Cutoff loops can become filled with water, forming isolate curve lake(Reynolds et al., 2012). Two type of stream cut-off are known (Figure 9) (Surian and Rinaldi, 2003):

1. *Chute cut-off* (A). If a stream in a meander loop shortens its course by cutting a new channel along a swale of point bar.

2. *Neck cut-off* (B). If a stream cuts a new channel through the narrow neck between two meander loops.

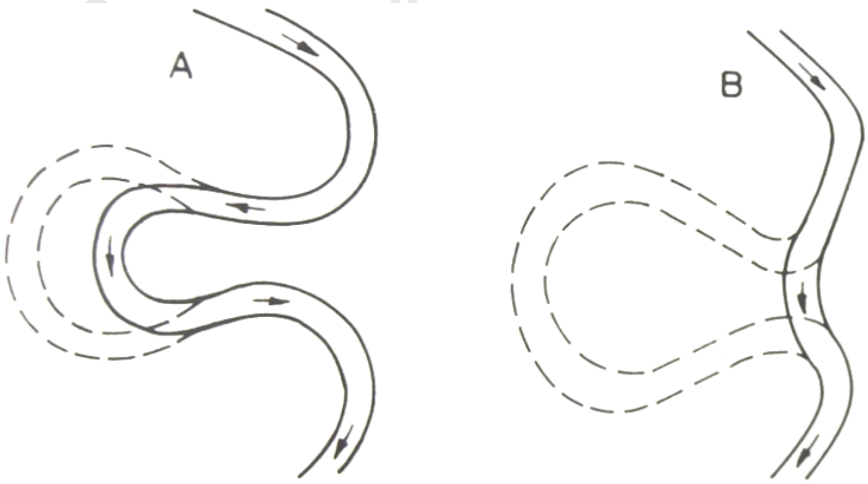

Figure 9 Diagram showing three modes of abandoning river channels. A Chute cut-off; B Neck cut-off (Surian and Rinaldi, 2003).

The abandoned channels are slowly filled and sealed at both ends of oxbow lake. In the beginning, sedimentation is rather rapid at and near the ends of the cut-off lakes. Some suspended material is introduced during overbank flows. Mainly clayey sediments and organic matter are deposit until filling is complete. This process produces a sequence of thick clay sediments in the form of clay plugs, whose thickness is controlled by the depth of abandoned channel. At the end of channel-fill deposit sandy plugs are present. Clay and silt is most abundant.

Channel-fill deposits produce by two different types of cut-off show some identifying characteristics (Figure 10). Channel-fills deposits from chute cut-off (A) are less curved. The absolute size depends upon the width of river and the size of the meanders. Bed load continues to be deposited for longer periods. The phase of clay sedimentation is short, so clay plug of short dimensions are produced. Lithology is mainly silty sand, sand and clay. In the lower part sand and clay units alternated.

Channel-fill deposits from neck cut-offs (B) are strongly curved and larger. The cut-off is complete at an early state; after that no bed load is available. The filling done by overbank flows and fine grain clay sequence is deposited.

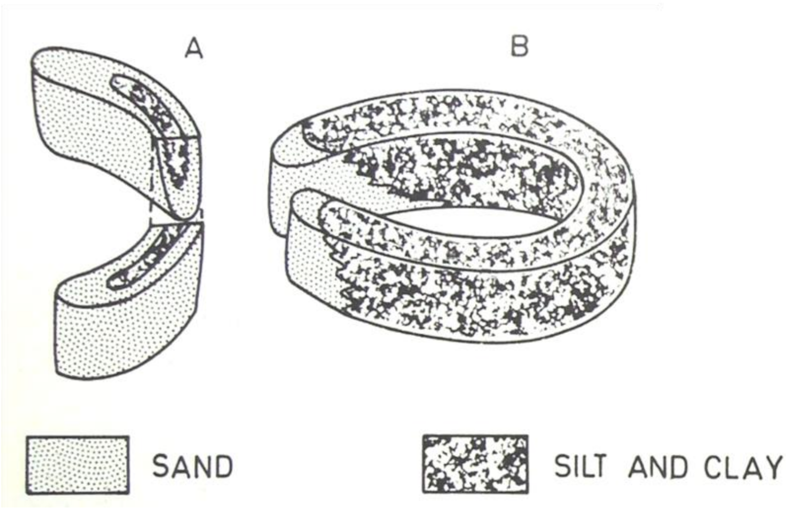

Figure 10 Various types of channel –fill deposits. A Chute cut-off; B neck cut-off (Surian and Rinaldi, 2003).

6) Floodplain

All rivers on gentle plains have floodplains beside the channel. Floodplains represent the area covered with water when the river floods out during overbank flow.

Overbank flooding deposits not only muddy sediments, but also an abundant amount of sand. Generally, fine sand, silt, and clay layers are deposited, and the sequence resembles very much the sequence in natural levee deposit. Sedimentation begins with a sand layer, becoming silty upward. Climbing ripple lamination is abundantly developed. Small-scale cross bedding and horizontal bedding are other important bedding types. Plant debris is abundant. The clay layer is generally show mud cracks. Near the surface carbonate concretions and iron concretions may be form in areas with high rate evaporation (Surian and Rinaldi, 2003).

7) River Terrace

Many rivers have stranded older floodplains, called terraces, perched above and outside the current floodplain. The river terrace can be influenced by one or both of tectonic uplift and climate change. The dominant mechanism is erosion on the earth's surface. During the time of erosion, the river is incised on the previous floodplain and become river terrace. It is common to find matching terrace levels on either side of the existing floodplain. This particular stretch of river lacks obvious terraces.

2.1.3 Principle of aerial photograph interpretation

The geomorphic unit can be distinguishing by elements of aerial photo interpretation in Figure 11. (RSCC, 1998).

A. Basic - 1st Order

Tone/Color

Tone can be defined as each distinguishable variation from white to black (shade of grey). Color may be defined as each distinguishable variation on an image produced by a multitude of combinations of hue, value and chroma.

Resolution

Resolution can be defined as the ability of the entire photographic system, including lens, exposure, processing, and other factors, to render a sharply defined image. Photo interpreters often talk about resolution in terms of ground resolved distance which is the smallest normal contrast object that can be identified and measured.

B. 2nd Order - Geometric Arrangements of Tone/Color

Size

Size can be important in discriminating objects and features. In the use of size as a diagnostic characteristic both the relative and absolute sizes of objects can be important. Size can also be used in judging the significance of objects and features. The size of the crowns of trees can be related to board feet that may be cut for specific species in managed forests. The size of agricultural fields can be related to water use in arid areas, or the amount of fertilizers used.

Shape

The shape of objects/ features can provide diagnostic clues that aid identification. Man-made features have straight edges, natural features tend not to.

2nd. Order - Spatial Arrangement of Tone/Color

Texture

Texture is the frequency of change and arrangement of tones. This is a micro image characteristic. The visual impression of smoothness or roughness of an area can often be a valuable clue in image interpretation. Still water bodies are typically fine textured, grass medium, brush rough.

Pattern

Pattern is the spatial arrangement of objects. Patterns can be either man-made or natural. Pattern can also be important in geologic or geomorphologic analysis; drainage pattern can reveal a great deal about the lithology and geologic structural patterns of the underlying strata. Dendritic drainage patterns develop on flat bedded sediments, radial on domes, linear or trellis in areas with faults, etc..

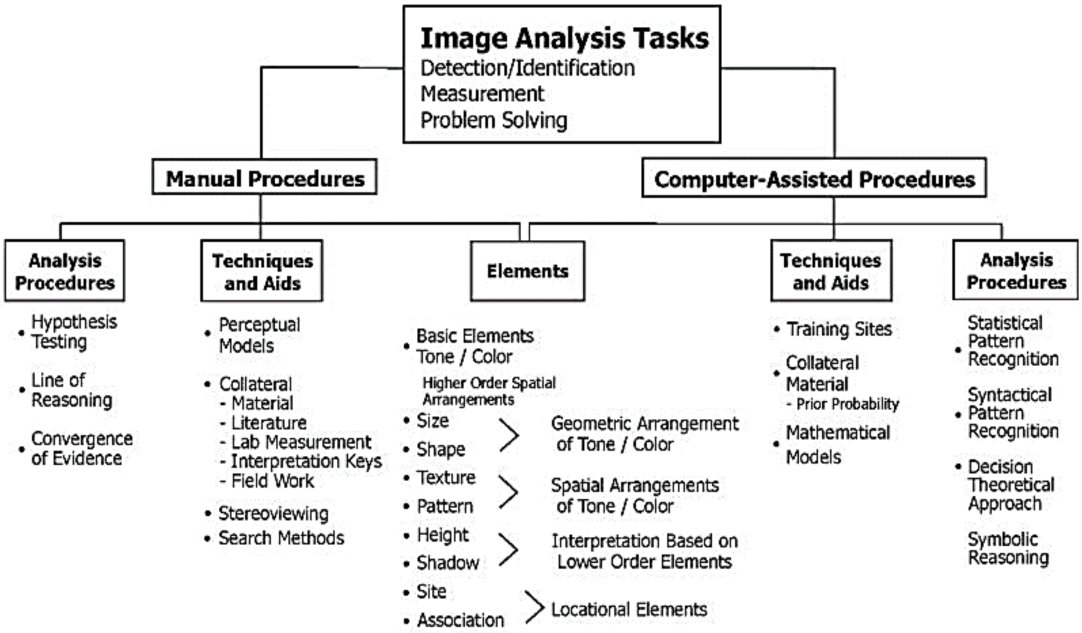

Figure 11 Elements of Air photo/Image Interpretation (RSCC, 1998).

2.2 Geomorphic planform parameter analysis

The geomorphic planform parameters include index (SI), radius of curvature (Rc) which consists of meander wavelength (Lm), channel width (W) and channel migration.

2.2.1 Sinuosity index (SI)

Channel pattern is a reflection of channel adjustment to channel gradient and cross-section, and seem strongly controlled by the amount of sediment load and discharge. Three most recognized channel patterns are straight, braided and meandering (Figure 14) (Hooke, 2007), and they were categorized by sinuosity index (SI). Leopold (1964) distinguished meandering from straight and braided rivers on the basis of sinuosity, defined as a ratio of channel length to down-valley distance. River having a sinuosity of 1.5 or greater are meandering; those below 1.5 are straight and braided (Surian and Rinaldi, 2003).

According to the static and dynamic characteristics, alluvial river patterns are in general categorized in this thesis follow the classification by (Dey, 2014).

1. Straight rivers have minimal sinuosity (< 1.1) at the bank full conditions. Usually, rivers, as simple straight open channels, exist only over short reaches; while long, straight rivers seldom occur in nature. At low flow stages, alluvial bars exist on

either side of the stream. The thalweg may move with alternate bars as they migrate downstream.

2. Meandering rivers (sinuosity >1.5) consist of a series of turns with alternate curvatures connected at the points of inflection or by short straight crossings. They have a relatively low gradient. The natural meandering rivers are quite unstable due to predominant bank erosion downstream of concave banks. Deeper flows are prevalent in the bends and higher velocities along the outer concave banks. The flow depth at crossings is relatively shallow compared to that at bends. Meandering rivers migrate gradually and hence sinuosity tends to increase. Eventually, the channel forms almost a closed loop and the meander gets often cutoff during a flood. Sinuosity index between 1.1 and 1.5 are sinuous, and meandering rivers have a sinuosity of greater than 1.5. Therefore, sinuous rivers are the transition between straight and meandering rivers.

3. Braided rivers are wide and shallow and divided to branches by a number of semi-stable or unstable bars or islands. More specifically, braided river can be defined as one that flows in two or more channels around alluvial bars or islands. They have a braided look at the low flow stages with exposed bars, but all or some of the bars are submerged during the high flow stages. However, in most of the occasions, the branching is such that one is the main stream and the others are subsidiary channels. The main stream is relatively stable, but it can change its route under some flow and sediment transport conditions, while the subsidiary channels are quite unstable and often change during floods.

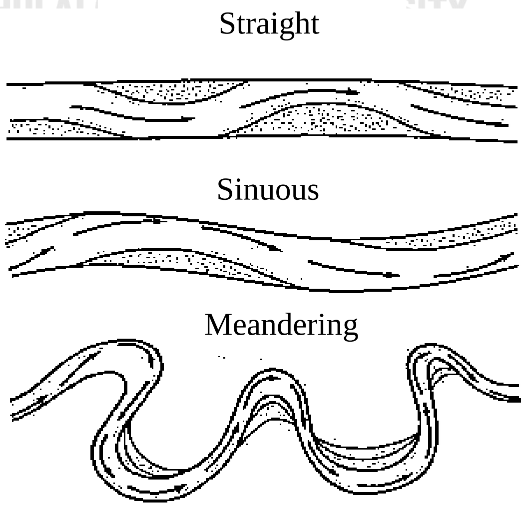

Figure 12 Classification of rivers based on the degree of sinuosity (Hooke, 2007)

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Sinuosity is a commonly used indicator of channel behavior (E. J. Hickin, 1974 , Ibisate et al., 2013). Sinuosity was calculated as the ratio between channel length and straight-line valley length. (Leigh, 2006). To determine the sinuosity of the river, the sinuosity index was used (Friend P. F., 1993, Hooke, 2007). Sinuosity indices are calculated from the map or from an aerial photograph measured over a distance called the reach. The length of the stream is measured by channel length over the reach (AB), while the bottom value of the ratio is the down valley length or displacement between two points on it defining the reach (CD) in Figure 13(a).

2.2.2 Radius of Curvature (Rc)

To determine the Radius of Curvature (Rc) of the Mun River, the one of a pioneer method plotted average annual erosion rate versus Rc/channel width of meander bend of the seventeen river in Sweden (Williams, 1986), the Red and Mississippi River (Thorne, 1991) and Beatton River (Neal, 2004). Rc is commonly used to evaluate channel stability. The radius of curvature and meander amplitude related with a function of channel width. The plan-view sketch of idealized river meander and the geomorphic parameters were undertaken for calculation such as wavelength and radius of curvature (Figure 13 b). The Rc value calculate from meander wavelength (Lm) and channel sinuosity (ratio of channel distance to down valley distance) (SI) by this relation (Williams, 1986). Then the result of Rc in each period of time were compared, and the result of Rc/channel width (W) values were plotted against migration rate per year to examine channel stability.

$$Rc = \frac{LmSI^{1.5}}{13(SI-1)^{0.5}}$$

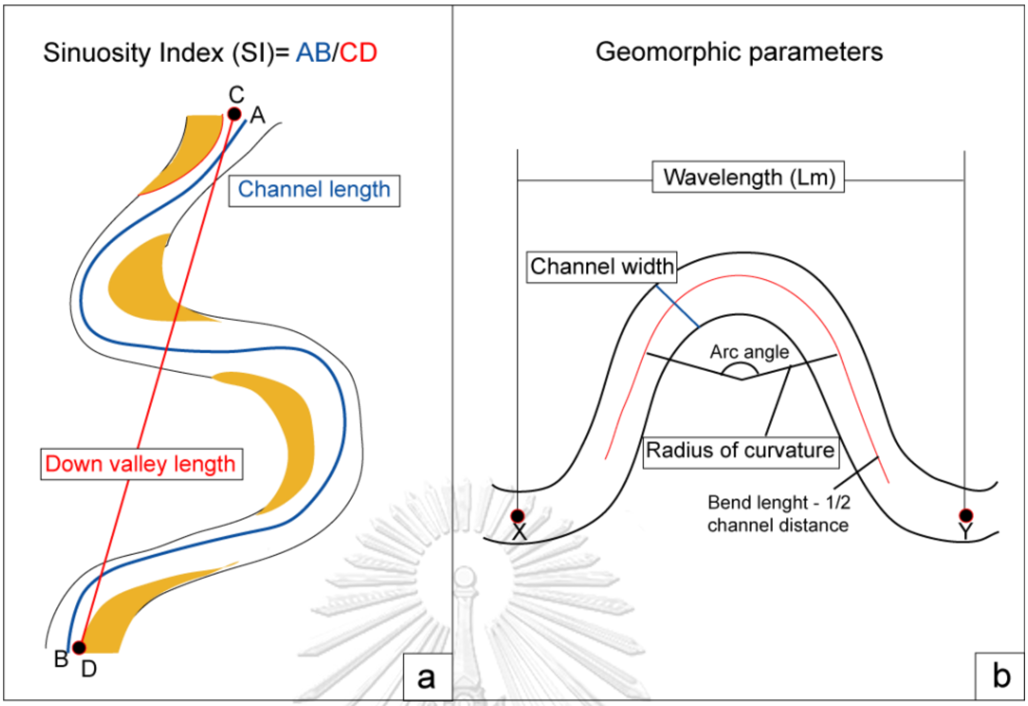


Figure 13 The plan-view sketch of the geomorphic planform parameters calculated for SI and Rc (Nimnate et al., 2017, Williams, 1986).

2.2.3 Channel migration

Lateral migration rate carried out from bank-line variation (shifting bank-line) over period of time interpreted from aerial photograph and satellite image (Melville and Coleman, 2000). The lateral migration rate decreased with decreasing of flow energy (Richard et al., 2005). The channel migration is a discontinuous process within any single bend, based on short- term measurements using erosion pins or aerial photographs, are highly suspect.

Rates of lateral migration on any river can be expressed by:

$$M\ (\text{migration}) = f(Q, s, c, h, v, r_m/w_m)$$

where Q, s, c, h, v and r_m/w_m are, respectively, a discharge factor, water-surface slope, character of the boundary material, height of the concave bank, bank vegetation, and the ratio radius of channel curvature to channel width. The discharge factor is a surrogate variable for the intensity of boundary shear and flow velocity. Other things being constant, the rate of lateral migration will increase as discharge increases.

Increases in water-surface slope will also increase the rate of lateral migration. The resistance to erosion offered by the material of the concave bank is also clearly an important factor affecting the migration. The height of the concave bank will similarly affect the rate of lateral migration; other things being constant, the rate of lateral migration will decline as bank height increases, because a greater amount of material must be eroded per unit time to maintain the level of migration (Edward J. Hickin and Nanson, April 1975).

Nanson and Hickin (1983) found that the channel migration rates based on observations from a single reach of river should be seen, and the influences of bend planform are stream power, resistance of bank materials to lateral erosion, the height of the convex bank, the degree of incision, the sediment supply rate.

The texture (grain size class) of the bank material is the one of important factor of the lateral erosion. From the Figure 14 the various type of the bank material from clay to boulder size, the lowest of the coefficient of resistance to lateral erosion is the very fine sand and silt (Melville and Coleman, 2000).

The discontinuous nature of channel migration means that predictions of migration rate for individual bend based on short term measurement (from the time lapsed aerial photography over 20 or 30 years) are highly suspect. Theses short-run fluctuations in migration rates are implied in the floodplain from the imbalance between the rate of cut bank erosion rate and the rate of point bar sediment accumulation (Nanson and Hickin, 1983).

Qualitative prediction of lateral instability and erosion rates for channel can be carried out from aerial photographs or topographic map indicating bank line variation over a period of time. The change in response to variations in balances of sediment supply and sediment transport capacity. An increase in flow rate or decrease in sediment load can produce a reduction in channel slope resulting in an increase in tendency for the channel to wander and increased lateral bank erosion rates (Melville and Coleman, 2000).

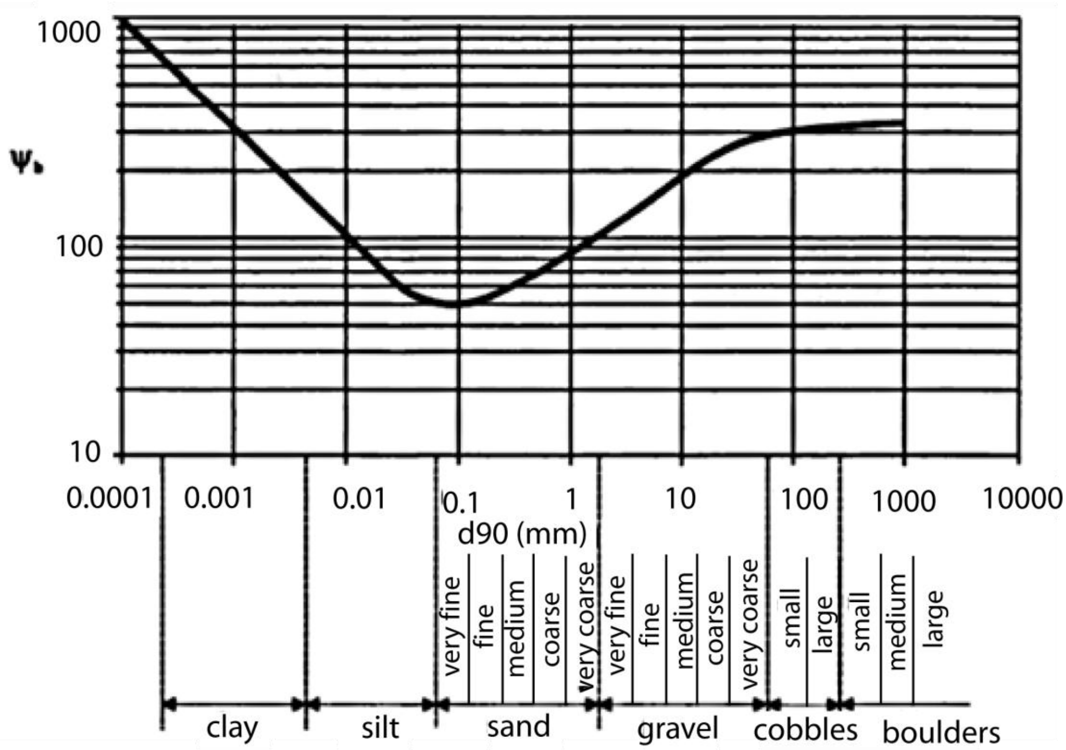


Figure 14 Coefficient of resistance to lateral erosion as a function of the texture of outer-bank sediments (Melville and Coleman, 2000).

2.3 Shallow geophysical survey in fluvial sediment

2.3.1 Ground Penetrating Radar (GRP)

Based on GPR interpretation, the image is essential to understand the nature and origin of reflections and to recognize reflection patterns characteristic of specific sedimentary deposits. Radar facies is defined as the sum of all characteristics of a reflection pattern produced by a specific rock formation or a sedimentary sequence. Both structural and textural features in the subsurface influence the radar response and produce characteristic effects in the radar observations. These effects are called radar facies elements. All radar facies elements can be involved in recognizing the reflection patterns that are characteristic of certain sedimentary depositional environments (van Overmeeren, 1998).

The determination of the character and geological history of sedimentary rocks and their depositional environment from radar images is defined as radar stratigraphy. The objective of radar stratigraphic interpretation methods is to recognize radar facies reflection patterns and to correlate these with specific sedimentary environments. The diagram in Figure 15 gives an example to illustrate this concept.

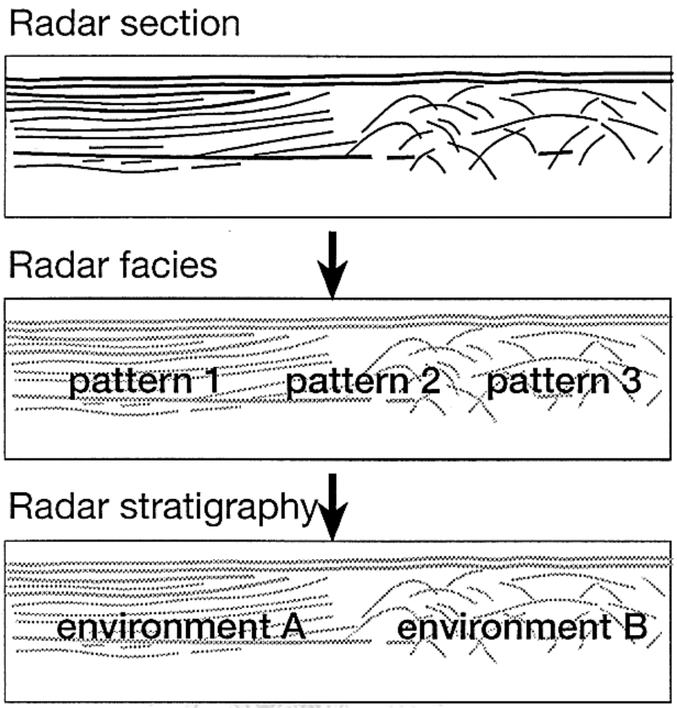


Figure 15 Radar stratigraphy interpretation procedures.
(Modified from Van Overmeren, 1998)

In the Fluvial environment, Sedimentation by meandering rivers is arranged more orderly in the point bars, which are produced by erosion in the outer bend of the meander and deposition in the inner bend. Point bars are characterized by a fining-upward sequence and have a well-defined sigmoidal internal structure. The sandy point-bar deposits are generally overlain by finer sediments silts and clays that were deposited during inundation. Quite often, this case limits the applicability of GPR (van Overmeeren, 1998).

Characteristic patterns of the meandering river, the radar facies of both the floodplain and the channels are clearly different between channel fill and floodplain. The channel fill of the abandoned meander is characterized by horizontal reflections (representing a horizontal fill of clayey sediments), but the floodplain of the meandering river large-scale parallel dipping reflections were represented point bar.

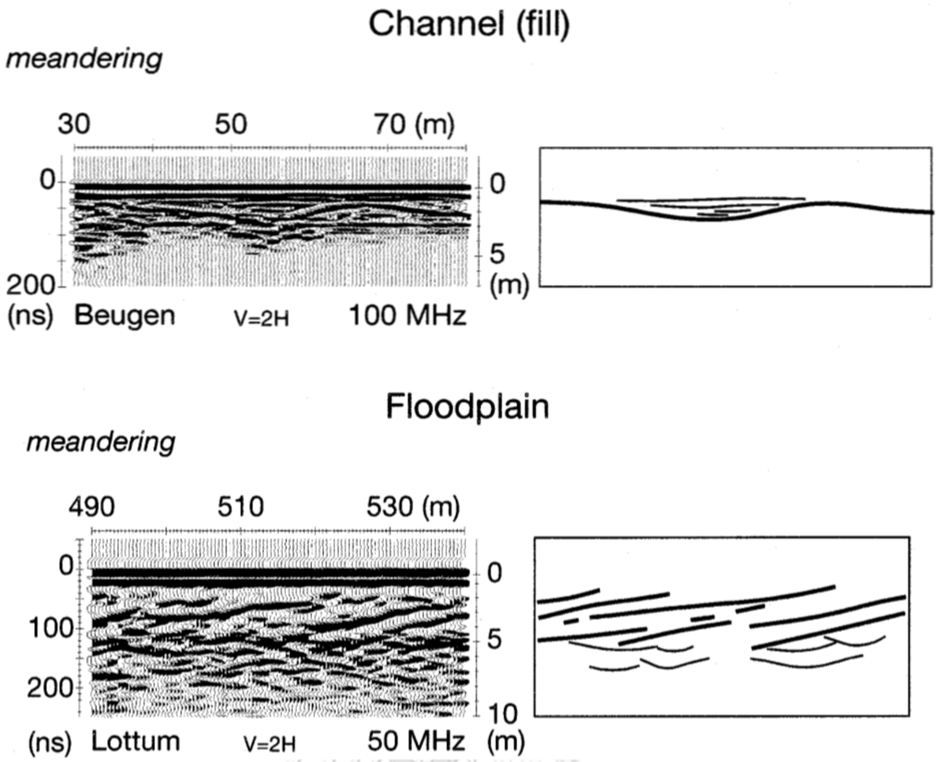
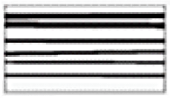
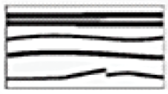
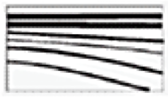
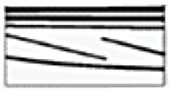
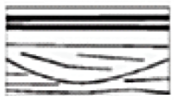


Figure 16 Radar facies of charateristic reflection pattern from fluvial paleoenvironment of meandering river channal (fill) and floodplain (Vandenberghe and van Overmeeren, 1999).

Hickin et al (2009) studied fluvial architectural analysis which is linking fluvial style with preserved subsurface sedimentology of a bar platform and channel bend on the floodplain of a poorly organized wandering gravel-bed river in Northeast British Columbia, Canada. The radar profiles interpretation results in the differentiation of eight radar facies, one radar element, and several major bounding reflections (Table 2). The facies and the element constitute four groups: (1) continuous, horizontal to sub-horizontal reflections; (2) clinoform reflections; (3) discontinuous reflections; and (4) concave-up element.

Table 2 Four groups of radar facies and their interpretation
(A. S. Hickin et al., 2009)

Group	Catergory	Description	Interpretation	Schematic Example
1 Continuous Horizontal to Subhorizontal	Facies 1	Laterally continuous (10-70m) parallel, uniform, horizontal to subhorizontal	Well stratified, horizontal bedding, vertical accretion, hirzontal component of cross-bedding	
	Facies 2	Laterally continuous (10-70m) non-uniformt parallel to subparallel	Moderately stratified, subhorizontal bedding, vertical accretion, downstream accretion	
2 Clinoform	Facies 3	Laterally continuous (15-60m) low-angle (1-20 degree)	Well to moderately stratified, dipping bedding, lateral or downstream accretion, migrating bar or channel filll	
	Facies 4	Moderlately continuous (5-30m) incline(5-20 degree), shringed reflection	Well to moderately stratified, lateral accretion, slipface of migrating bedform	
	Facies 5	Short (10-15m), oblique tangential or parallel, inclined (15-30 degree) reflection	Moderately to poorly stratified, lateral accretion, slipface of cutbank	
3 Discontinuous	Facies 6	Discontinuous (5-15m), hummocky or disrupted reflection	Abandant stratified to massive deposit	
	Facies 7	Discontinuous (5-10m), random, chaotic reflection	Crudely stratified to massive deposit	
	Facies 8	Discontinuous, abundant diffracted reflection	Abandant point source diffraction from object such as log or cobbles	
4 Concave-up Lower Boundary	Facies 9	Small to medium-scale (10-30m), concave-up lower bounding surface	Sediment-filled chute or channel	

2.3.2 Electrical Resistivity Tomography (ERT)

The resistivity survey using the arrangement of the four electrodes used to make an individual resistivity measurement affects the measurement's depth of investigation, vertical and horizontal resolution and sensitivity to noise. The resistivity profiles should be verified by qualitative comparison with subsurface information (e.g. drill core, electric logs, GPR, shallow seismic, exposures). The resistivity of sediments is altered by the quantity and chemistry of pore space moisture. The interpretation for sedimentological studies in natural settings should be based on the relationship between grain size and resistivity. Under any particular set of moisture conditions, gravel always has a higher resistivity than sand. Similarly, sand has a higher resistivity than silt, and silt has a higher resistivity than clay (Baines, 2002).

The ERT survey arranged the electrodes along a survey line. The distance between the electrodes is called the electrode spacing. Electrical contact with the ground is achieved by connecting each electrode to a stainless-steel stake driven 20 cm into the ground. Depth of investigation for the survey is slightly less than one-fifth of the total length of the survey line. Resolution is equal to approximately one-half of the electrode spacing. Depth and resolution show an inverse relationship dependent on the electrode spacing and the total number of electrodes (Baines, 2002).

The advantage of resistivity survey is that it can be used to detect subsurface changes in the lithology below clay and silt layers, a situation where other techniques as GPR do not. This method can determine the thickness and lithology of the filled sediments. Another advantage is fast and cost-effective, noninvasive strata. The profiles show accurately lithology, stratigraphy fluvial deposits. For example, sand channel-fills buried in mud appear as channel-shaped high-resistivity anomalies, so this geophysical method prove to be a highly useful tool for investigating fluvial and other depositional successions (Baines, 2002) (Figure 17).

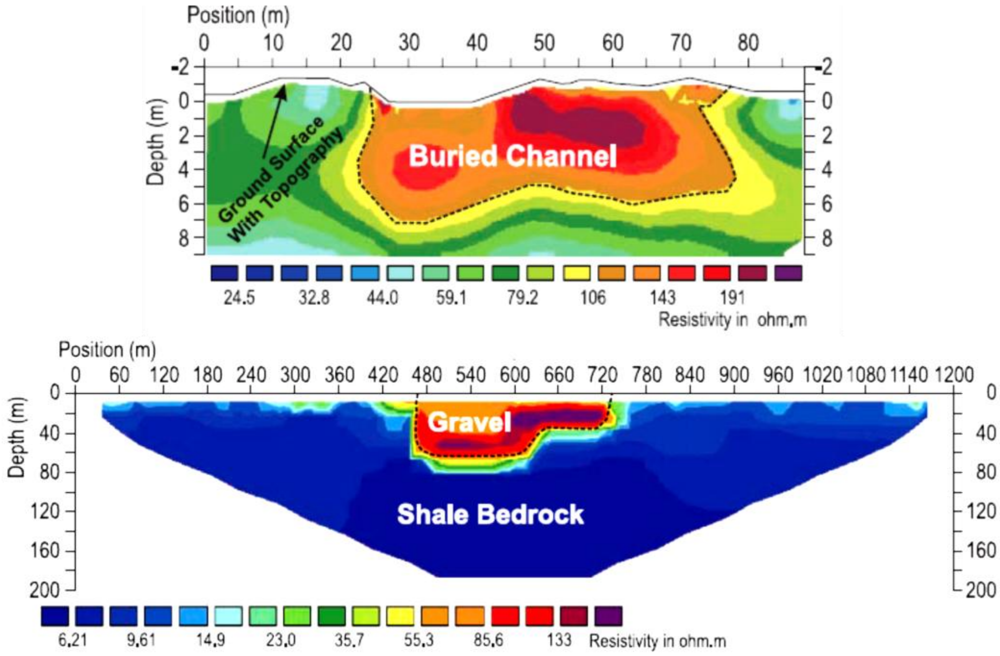


Figure 17 The ERGI profile of sand-fill Beavertail channel in the anstromosing reach of the Upper Columbia River (upper). The 58 m of gravel above shale bedrock in a Late –Pieistocene valley-fill of Saskachewan, Canada (lower) (Baines, 2002).

CHAPTER III
Methodology

The research procedures of this research can be divided into three steps – office work, field investigation and laboratory analysis and it was summarized in Figure 18. The detail of each step was described below.

This research will publish on two international journal. The result of aerial photo interpretation and geomorphic planform parameter analysis of the Mun River has been published on the Environmental Earth Sciences Journal, Volume 76, 28 April 2017 under the title **"Geomorphic criteria for distinguishing and locating abandoned channels from upstream part of Mun River, Khorat Plateau, northeastern Thailand"**(DOI 10.1007/s12665-017-6657-y).

Moreover, the results from sedimentological and shallow geophysical surveys were accept from Jurnal Open Geosciences on 24 October 2017 under the title **"Imaging and locating paleo-channels using geophysical data from meandering system of the Mun River, Khorat Plateau, Northeastern Thailand"**.

3.1 Office work

3.1.1 Literature reviews

This step was searching and reviewing previous literatures. The evolution and geomorphological investigation of rivers (meandering, braided and anastomosing river patterns) were reviewed. Several geophysical surveys especially resistivity survey and ground penetrating radar on the deposition of fluvial systems. The result of radar reflection and apparent resistivity inversion model from Electrical resistivity survey were using for case study. All these were employed for research planning and further discussions and conclusions.

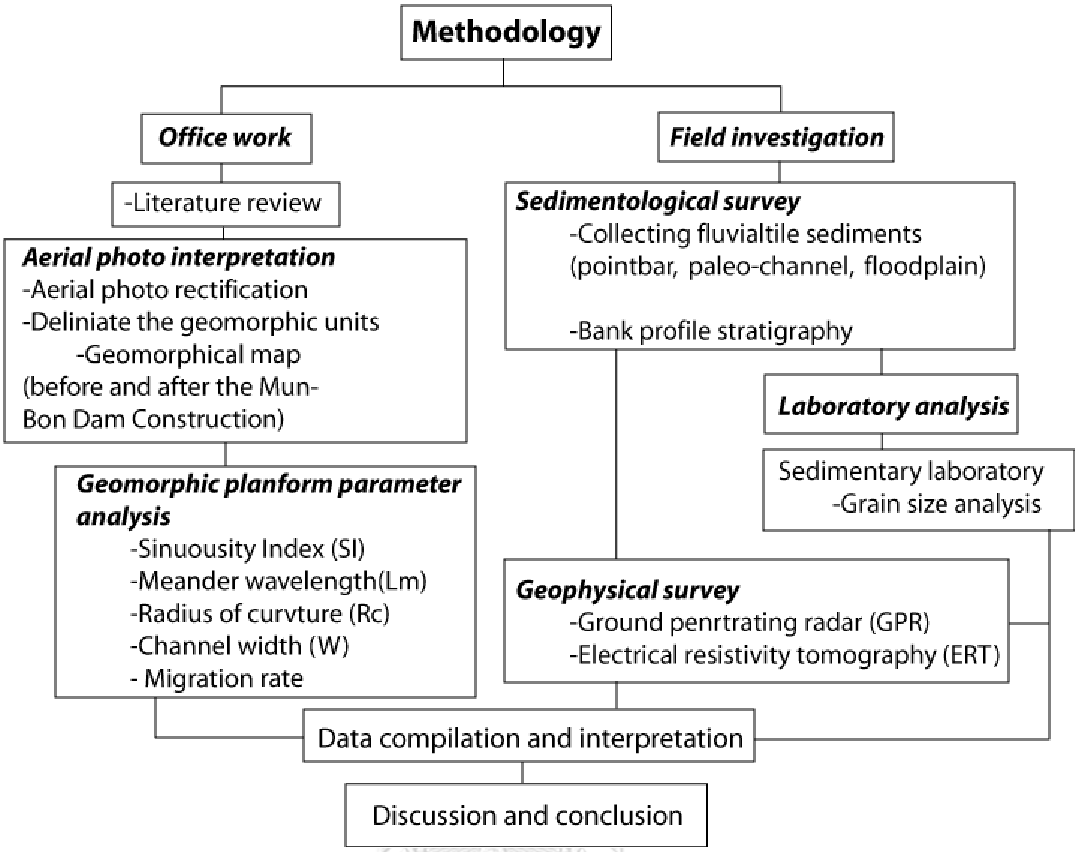


Figure 18 The research framework was divided in to three parts as office work, field investigation and laboratory analysis.

Table 3 Data types and respective sources of data for determining geomorphologic changes and calculating geomorphic parameters were used in this study (Nimnate et al., 2017).

Data type	Acquitsition date	Resolution	Source
Aerial photographs	December 1974	Black and white photos Approx. scale 1:15,000	Royal Thai Survey Department
Aerial photographs	March 1986	Black and white photos Approx. scale 1:15,000	Royal Thai Survey Department
SPOT satellite imagery	March 2004	Multispectral (10-20m)	Geo-Informatics and Space Technology Development Agency
THEOS1 satellite imagery	April 2011	Multispectral (15m)	Geo-Informatics and Space Technology Development Agency
GoogleEarth	November 2015	Multispectral (1-2m)	Geo-Informatics and Space Technology Development Agency

3.1.2 Aerial photo interpretation

Series of aerial photograph, ortho images and satellite images covering the period of about 37 years (1974 to 2015) before and after the Mun Bon Dam construction were chosen. The detail of data type and source of data displays in Table 3 Comparison of geomorphic landform in the lower part of the study area that connected with the Mun Bon Dam was divided in five river reaches (Figure 19). The geomorphic unit as river, oxbow lakes and meander scars were compared in three periods of time as 1974, 1986, and 2011, respectively.

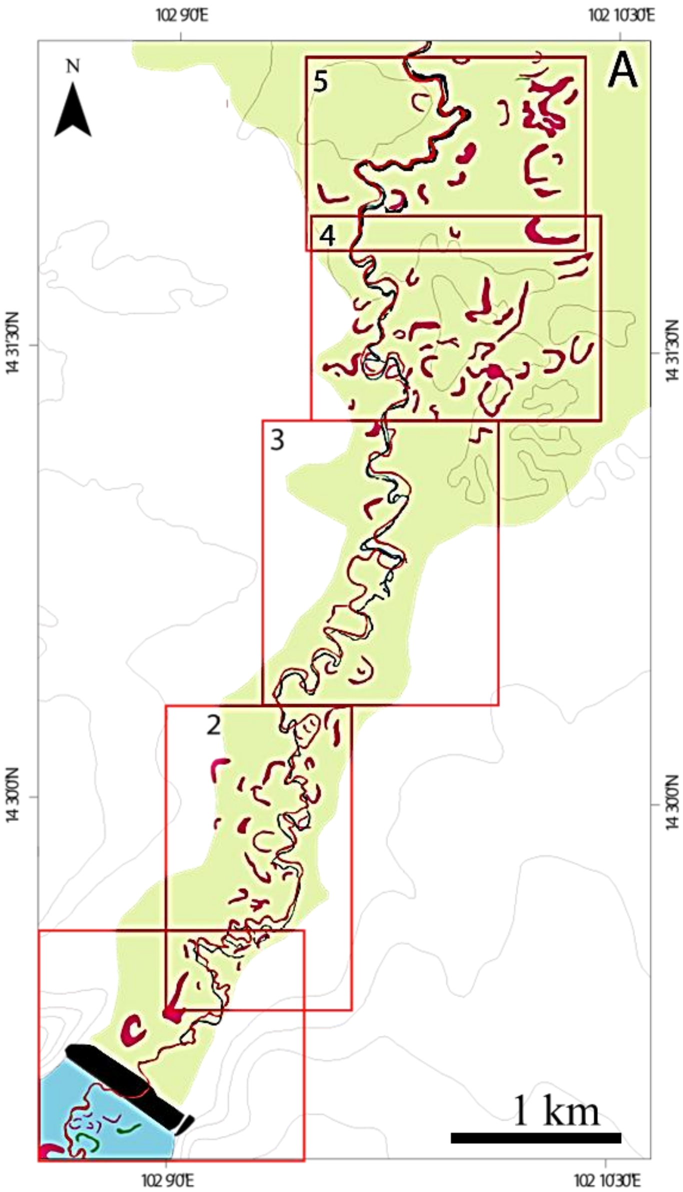


Figure 19 Five reaches were subdivided for analyzed the geomorphic unit from aerial photo interpretation (1974) (Nimnate et al., 2017).

Historical maps have the potential to provide much information on morphological changes of large rivers (Schumm, 1979). Geomorphic unit were analyzed by using aerial photos and satellite images in Figure 20. The historical analysis, covering a period of about 37 years (from 1974 to 2015), was carried out with a GIS (Ziliani and Surian, 2015).

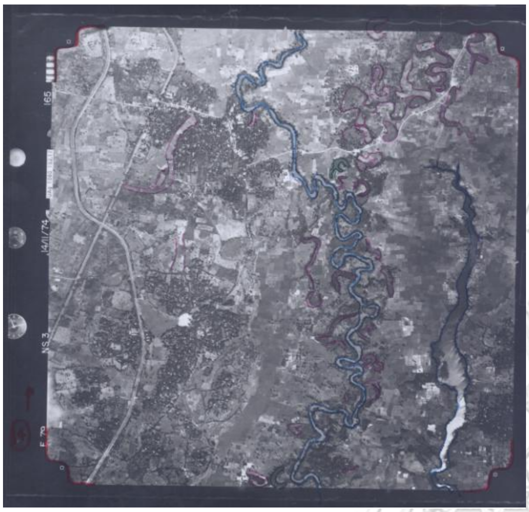



Figure 20 The printed versions of historical aerial photographs in 1974 scale 1:15,000 (left) and satellite image from THEOS1 Satellite image in 2011 (right) were used to examine the geomorphological change of the Mun River in Amphoe Khon Buri and Chok Chai.

3.1.3 Aerial photo rectification

The printed versions of historical aerial photographs covering the Mun River from the Mun Bon Dam (Amphoe Khon Buri) northward to Amphoe Chok Chai are available from the Royal Thai Survey. These photos were scanned and rectified using ArcGIS software. The geometric correction conducted on aerial photographs and satellite image for remove the geometric distortions from the raw pictures. Throughout the images in the exact landmark such as intersection of the road or man-made construction were identified for ground control points (GCPs). The acquiring criteria for this study is the low Root Mean Square Error (RMSE) of GCPs. The ArcGIS 9.3 software was applied for the GIS analysis, and the WGS1984 UTM (Zone 48N) coordinate system were carried out for all of the materials.

3.1.4 Delineate the geomorphic units

3.1.4.1 Geomorphic mapping

All of the natural landforms and man-made infrastructures will be identified by mirror stereoscope. The boundary of geomorphic units such as Oxbow lakes, meander scars and floodplain will be delineated carefully from images, then polygons of different years will also be digitized (Mithun et al., 2012). The Mun River channels were compared from different data source (1974, 1986, and 2011). The polygons of each geomorphic unit were drawn, and the results were digitized for geomorphological map. The comparing the landform from each period used to compared the geomorphological unit changing by appears or disappears by natural and manmade process. Moreover, the characteristic of meandering style of the Mun River in the study area was classified by using modified Brice classification in Figure 21

3.1.4.2. Geomorphic planform analysis

Regarding geomorphic planform analysis, the measurement of the sinuosity index (SI), meander wavelength (Lm), radius of curvature (Rc), channel width (W) and migration rate were analyzed and estimated for comparing river behavior (the recent Mun River) and the characteristic of river in the past (abandoned channels) by Arc Map 9.3 (GIS software) using measure tool for distance measurement. Adding line tool command was used for measuring size. Moreover, the effect of the Mun Bon Dam construction on the river planforms was determined during the pre (1974-1986) and post (2004-2015) dam construction. The analysis area was drawn by add line tool and got the detail of size by their property and calculated.

Down valley length, channel length, meander wavelength and channel width (see the plan-view sketch of the geomorphic planform parameters in Figure 22) were measured the size and length of recent river and paleo-channels (meandered scars) by adding line tool command in Arc Map 9.3 (GIS software). Eight river reaches were separated by the size and number of abandoned channels distributing on the Mun River floodplain and were measured the SI and channel width from the Mun Bon Dam to Chok Chai downtown area. The paleo-channels can be separated to two categories as small (≤ than 20 m) and medium-sized river channels (20 to 200 m) (David, 2003).

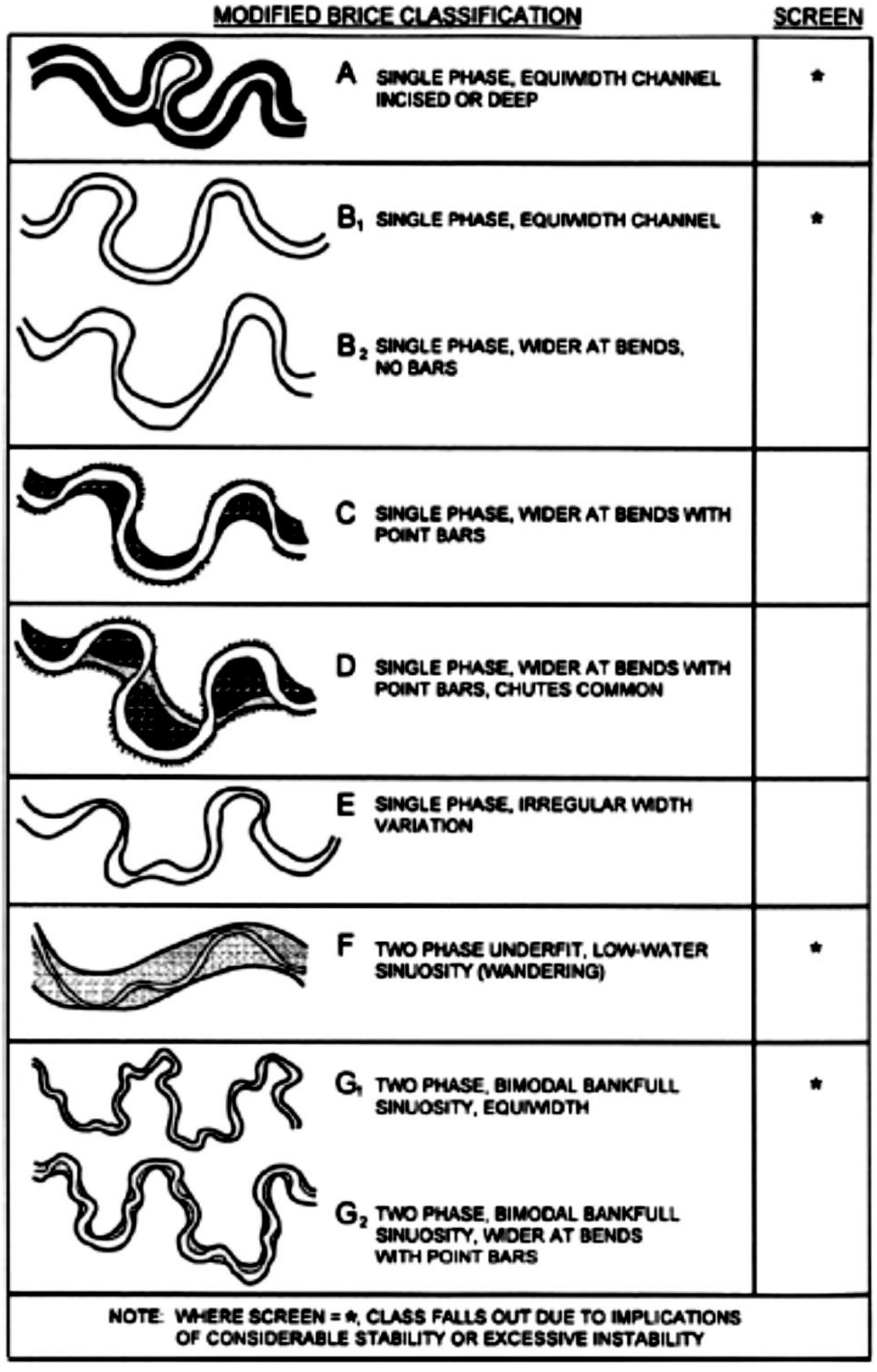


Figure 21 Classification of Meandering river (Hooke, 2007).

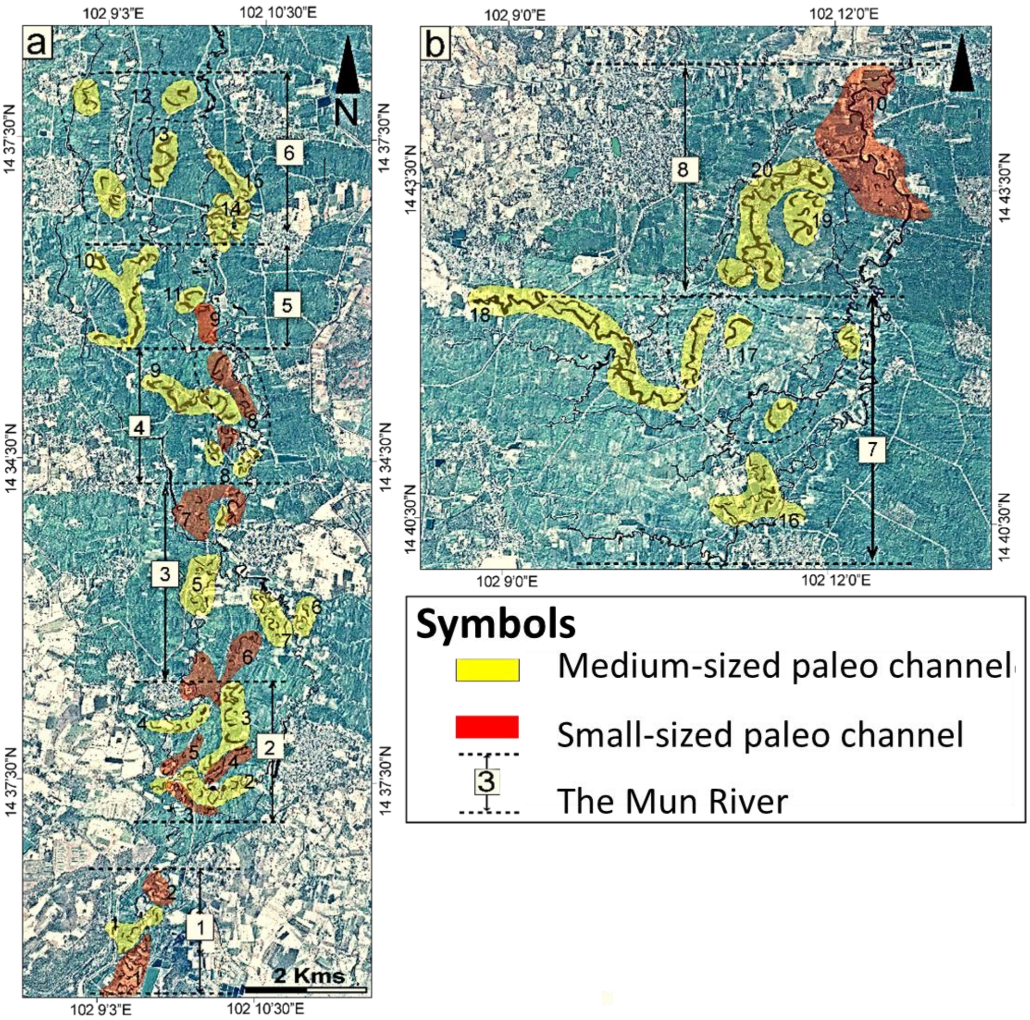


Figure 22 Eight river reaches were measured the Sinuosity Index and channel width of the Mun River and meandered scars from the Mun Bon Dam to Chok Chai downtown area (Nimnate et al., 2017).

I) Sinuosity index (SI) or meandering ratio

A common indicator of channel behavior is Sinuosity Index (SI) (Ferguson, 1975, Ibisate et al., 2013, Leigh, 2006). The SI was calculated from channel length divided by down valley length. In this work, we analyzed trend of sinuosity over time, changing in sinuosity on the recent Mun River (2011) comparison with the paleo-channel from eight reaches (1974) measured from aerial photo.

II) Radius of Curvature (Rc) – (channel width and meander wavelength)

Radius of curvature (Rc) is the relationship between channel width and meander wavelength, and it was calculated from the river planform in 1974, 1986, 2004 and

2015 from ten locations (Figure 23). Rc is normally measured from historic aerial photographs in comparison with the modern one (Nanson and Hickin, 1983). Rc displays degree of tightness of the river bends. Rc can be calculated from below equation (Williams, 1986).

If Rc value is high, the river bend will close to each other. On the other hand, wider bend shows low Rc value. Meander wavelength (Lm), channel width and channel sinuosity were measured, calculated and plotted as scattered graph to compare the changing of Rc of the Mun River bend overtime from 4 times (1974, 1986, 2004 and 2015). Based on channel width, the change of channel width of ten locations also was measured from the aerial photographs and satellite images.

$$Rc = \frac{LmSI^{1.5}}{13(SI-1)^{0.5}}$$

Finally, the channel stability is then derived from relationship between migration rate per year and radius of curvature/ channel width.

III) Lateral migration rate

Lateral migration rate carried out from bank-line variation (shifting bank-line) over period of time interpreted from aerial photograph and satellite image (Melville and Coleman, 2000). Meander migration rate per year of two periods (before and after the Mun Bon Dam construction) were measured and calculated, and the result was shown as graph. Moreover, this is one parameter for calculate channel stability which is mentioned before.

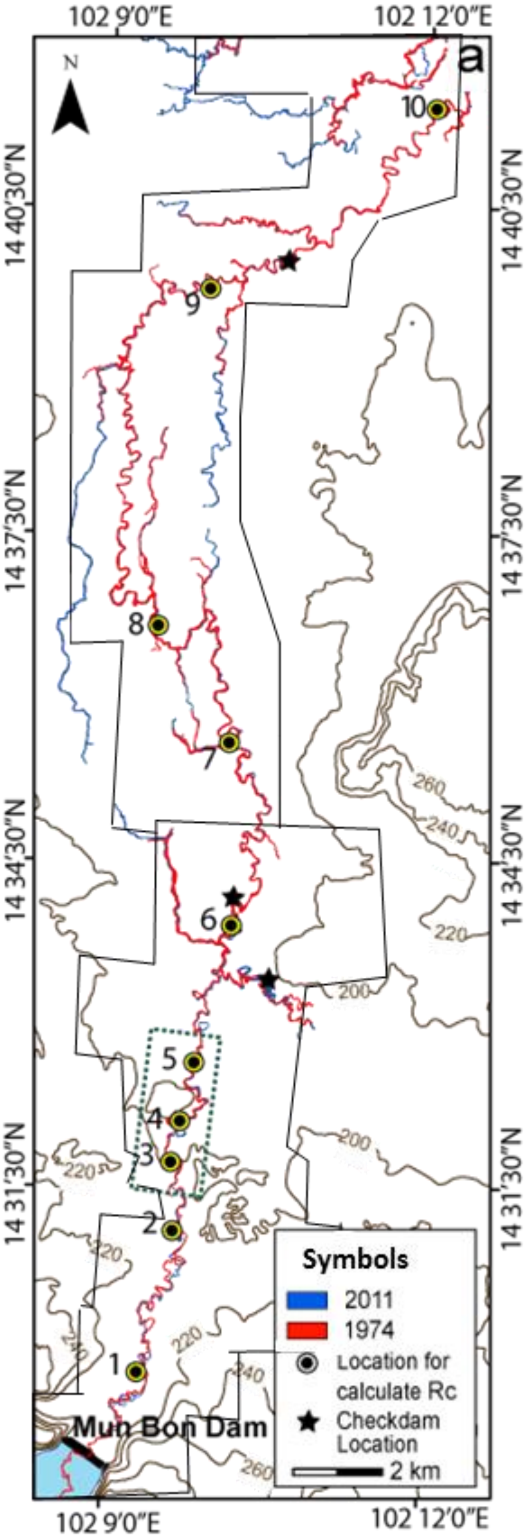


Figure 23 Geomorphic planform parameters such as SI, Rc/w and migration rate were measured, calculated and compared from ten locations of the Mun River before and after dam construction. The black line is limit of aerial photo data source (Nimnate et al., 2017).

3.1.5 Longitudinal profile

Longitudinal profile was estimated by the point elevation along the Mun River using Google Maps Find Altitude. The distance from the Mun Bon Dam to the Mun River distributaries in Chok Chai district were measured from total 22 point-elevations along the Mun River. All points were plotted the high above mean sea level (msl.) and the distance from the Mun Bon Dam (displacement). Five segments (approximately 5 km long per one segment) are expressed as meter per kilometer of topographic gradient.

3.2 Field investigation

Site investigation and description in detail of physical characteristics of sediments, this research was aimed to observe and collect the present and ancient fluvial sediments along the river bank, floodplain, point bar and paleo-channels. The geomorphological field check was carried out with one special aim to examine the accuracy of aerial photographs interpretation. Moreover, the subsurface stratigraphy profiles of the recent fluvial landforms such as point bar, meandered scar (paleo-channel) and floodplain were carried out for understanding about past fluvial succession. As regard shallow geophysical survey in this study, ground penetrating radar (GPR) and electrical resistivity tomography (ERT) were survey subsurface stratigraphy. The radar facies and ERT lithological classes were compiled. Sediment samples were gathered from different landform for verified geophysical survey. Sediment laboratory were conducted for analyze the sediment type. Finally, all data were integrated and correlated as result.

The major detail field investigation can be divided into 3 steps as 1) Collecting the fluviatile sediments, 2) Bank profile stratigraphy, and 3). Geophysical survey (GPR and ERT).

3.2.1 Study area and sites

The study area covers latitudes 14°29’N to 14°50’N, and longitudes 102°03’E to 102°18’E. The study area starts from the downstream of the Mun Bon Dam extending to about 50 km of Amphoe Khon Buri district and continues northward to Amphoe Chok Chai of Changwat Nakhon Ratchasima (Figure 2). Geologically, this area is occupied by clastic sedimentary rocks belonging to Mesozoic continental red beds of the Khorat Group. The bedrock are the Phu Phan and Khok Kruat formations which consists of siltstone, sandstone, conglomeritic sandstone and shale (Reesink et al., 2014). These bedrocks are overlain by unconsolidated Quaternary alluvial sediment which composes of gravel, sand, silt and clay along the Mun River channel and floodplain (Dheeradilok, 1993). At the upstream part of the Mun River where the Mun Bon Dam is located, river flows almost from the south to the north heading to Nakhon Ratchasima downtown. The Mun Bon earth dam is 32 m in height. The construction started in November 1986 and finished in January 1989 (Sorlalum and Mairaing, 2007). Dam obstructs the upstream part of the Mun River aiming to provide water supply for agriculture in the Nakhon Ratchasima and nearby provinces. The upstream catchment reservoir is located at narrow plain between sandstone beds of the Sao Khua and the Phu Phan formations of the Khorat Group. Many sand pits are operating at the downstream point bar of the river. It reveals numerous human pressures and interventions, leading to sediment flux modifications and resulting in morphologic changes.

The locations of the shallow geophysical survey (ERT and GPR) show on the geomorphic map (Figure 24). Eight resistivity survey lines and two GPR survey lines investigated along Paleo-channels (meandered scars), point bar and floodplain. The distribution of meandered scars interpreted from aerial photographs taken in 1974 display mostly on the Mun River floodplain. Location 1 is located near the Mun Bon Dam. The 120m-GPR survey line and 94m-resistivity survey line cover a dried channel and point bar. The location 2 surveyed at Ban Nong Sano. Three resistivity survey line (line 2.1 (94 m), 2.2 (94 m) and 2.3 (235 m)) display on the map. The 15m-GPR survey line and 94 resistivity survey investigate on paleo-channel at Ban Nong Sua Bong (location 3). The paleo-channel at Ban Muang Tako (location 4) was investigated by resistivity survey (235 m). The 235 m – resistivity line surveyed at Ban Mai Don Ket (location 5) on narrow paleo-channel group. The location 6 was examined at Ban Wang

Tabeak (Location 6) which is located on the right side of the Mun River floodplain. ERT line (585m-long) surveys on paleo-channel and floodplain.

The locations of sediment sampling and river bank profile description display on the Figure 25. The sediment logs were gathered as close as the survey lines and were collected by percussion drilling (red star symbol) and hand auger (black triangle symbol). Two banks profiles of the Mun River were investigated at Amphoe Chock Chai (Bank 1) and Ban Tha Ja Lhung (Bank 2). The detailed of each study sites will explain in the chapter IV (Results).

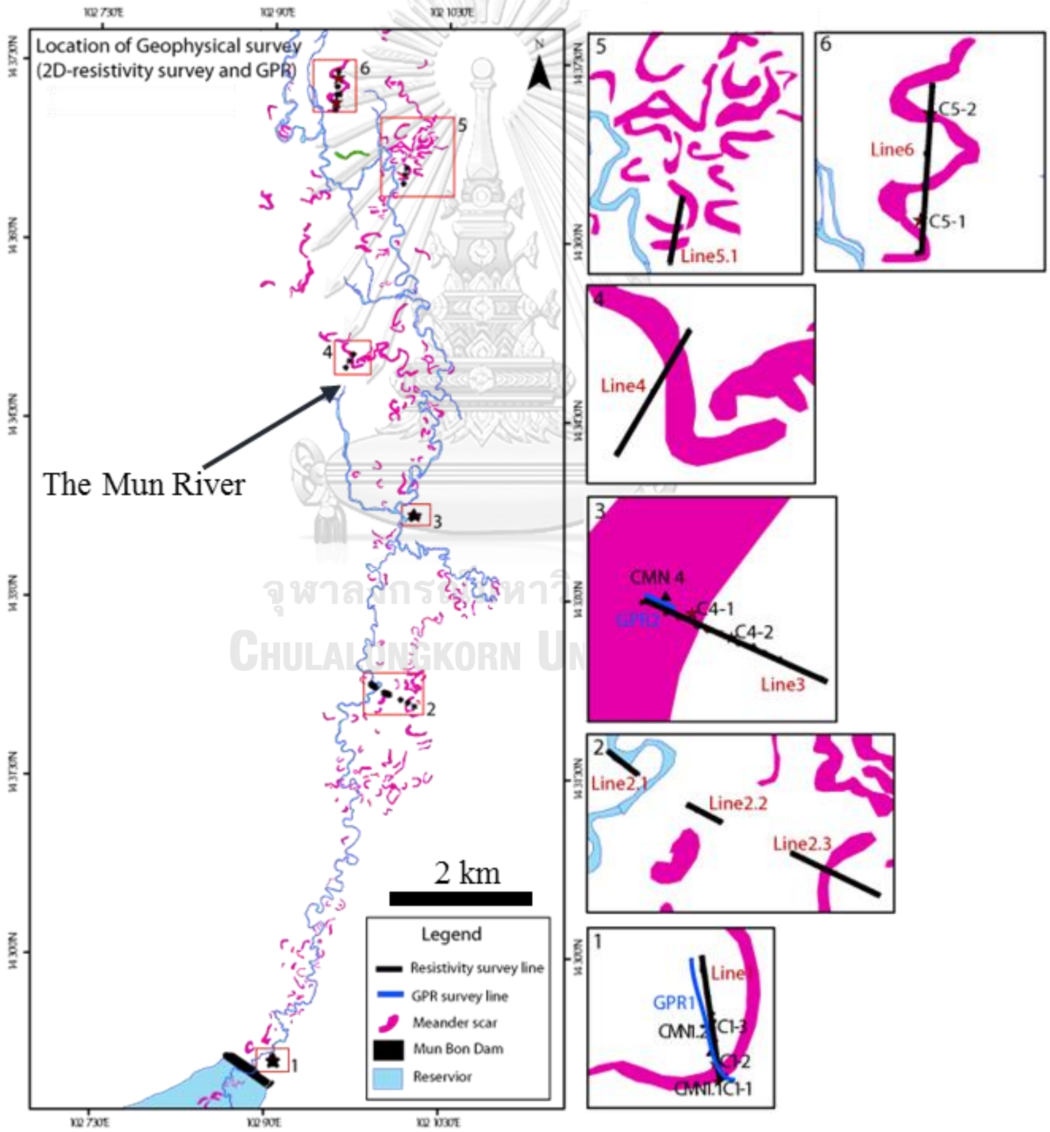


Figure 24 The map shows locations of Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR) survey on six sites along the Mun River.

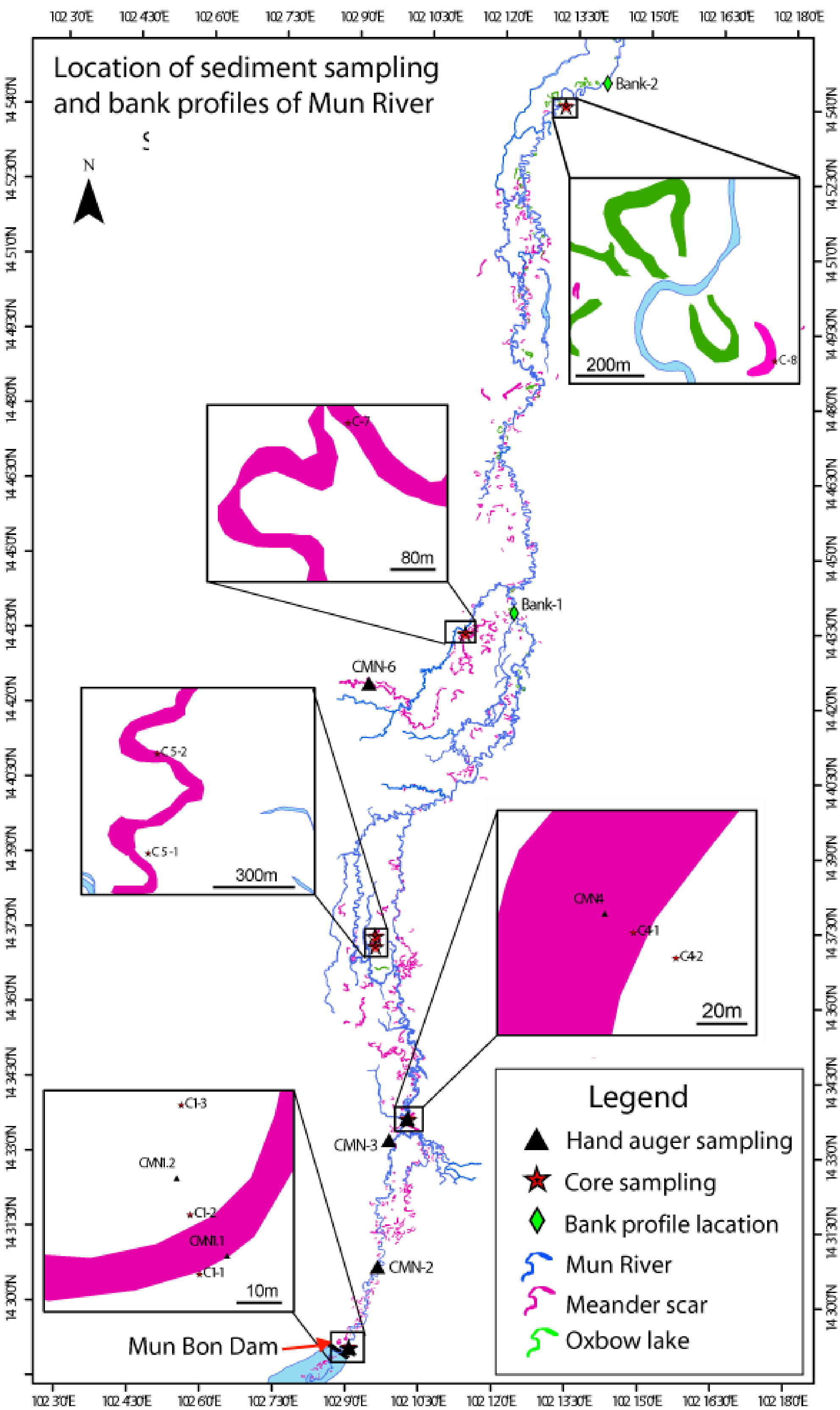


Figure 25 This map shows locations of sediment sampling by hand auger, coring and bank profiles in the study area.

3.2.1 Collecting the fluvial sediments

In this research, sediment samplings were collected from each morphological feature appears in the study area as the paleo-channel, point bar, floodplain and bank. Vertical variation in sediment samples were collected from each geomorphological unit by hand auger and percussion coring (Figure 26)

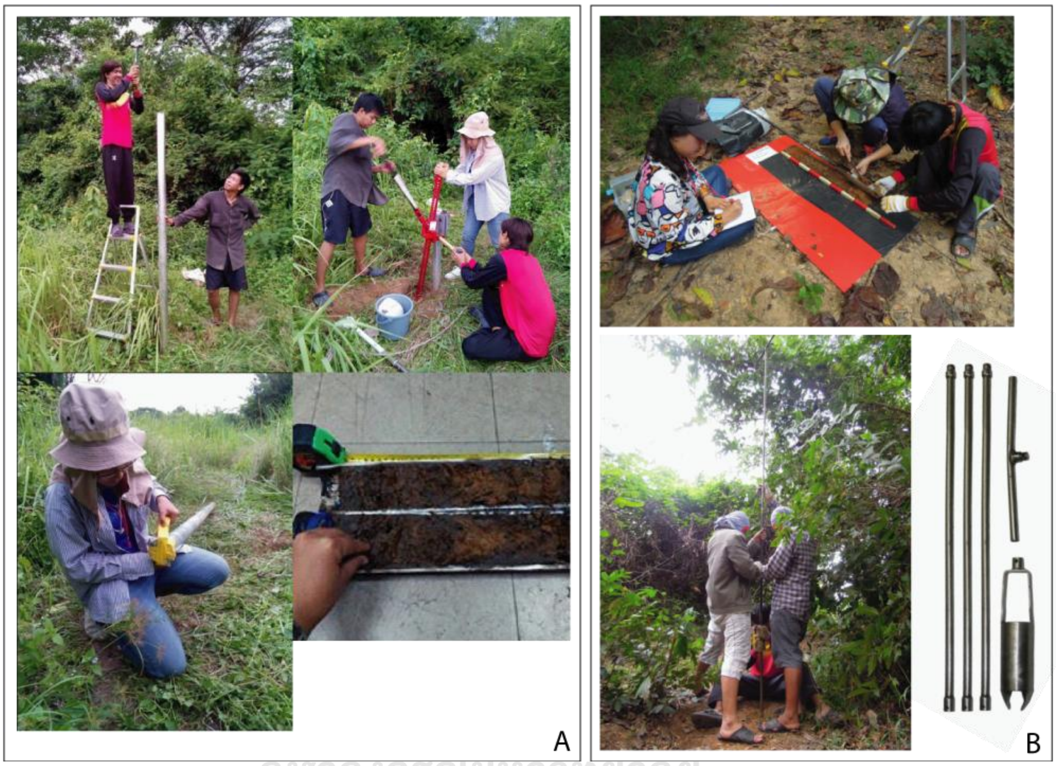


Figure 26 Sediment samples were collected by percussion coring 26 (A). The hand auger with sand bucket was used to collect unconsolidated sediment, and the description of sediment cores were considered in the field before select the sample for grain size analysis 26 (B).

Sedimentological investigation was carried out on each geomorphic unit nearest the survey line using a hand auger and percussion drilling from each geomorphic unit as paleo-channel, floodplain point bar and bank sediment during describe the bank profile. As for undisturbed sediment, the percussion cores were used hammer, aluminum tube with 3 inches diameter and hand jack. The aluminum tube was inserted in to the ground by hammer lifting until can’t pass through the sediment layer. Each core was plugged and wrapped with plasticine and tape in the field and brought back to the laboratory. Then all of the cores were cleaved by the metal cutter machine. Logging sediment layer by using sediment size, color and texture characteristics were conducted (Figure 26A).

Regarding drilling the sample by hand auger was done as deep as possible along ground penetrating radar and resistivity survey lines for correlate stratigraphy and lithology of each location. Samples from hand auger were preliminary described in the field and were picked from the same layer until it changed to another layer and installed it in zip-lock plastic bag brought back to the laboratory for grain size analysis (Figure 27).

Figure 27 Sediment samples from hand auger drilling were picked into the plastic bags.

3.2.2 Bank stratigraphy

Before entering the field, satellite image data covering the Mun River in the study area (Amphoe Khon Buri and Chok Chai) were chosen bank locations from the Google Earth and. The field sites used for this thesis were ultimately located by walking along the Mun River. The sites were available, the slope faces were trenched to get fresh exposures for better identification, description, and clear contacts between the beds (Peterson, 2009) (Figure 28.). Trenching was conducted in the bank side. Detailed descriptions of the stratigraphy were made at each site including the size, color, and texture. Samples were collected from the freshly trenched site. Every sediment layer was put in to plastic zip lock bag. All samples were kept isolated until it could be processed in the lab.

Figure 28 The bank site was trenched to get fresh exposures, and the detailed descriptions of the stratigraphy were made at each site including the size, color, and texture.

3.2.3 Geophysical survey

Shallow geophysical surveys were conducted where the areas are available in terms of accessibility. Ground penetrating radar (GPR) and electrical resistivity tomography (ERT) were assigned to obtain shallow subsurface stratigraphy (approximate depth to 5-20 m) and their relationships that may lead to understand the fluvial succession in the past. The history of avulsions of river was revealed from paleo-channels. Furthermore, GPR and ERT data could be directly correlated with sedimentary information derived from exposures, detailed drilling, and geomorphological data (Vandenberghe and van Overmeeren, 1999).

3.2.3.1 Ground penetrating radar (GPR)

GPR has been used as an electromagnetic surveying technique. It is a non-destructive method that analyses the underground propagation of high-frequency electromagnetic waves in the frequency range of 100 MHz to 1 GHz. The device is equipped with an emitting antenna that moves across the surface of the terrain, emitting very short temporal pulses. When these waves meet a dielectric contrast underground, the waves are reflected towards the surface, where their characteristics are measured with the aid of the receiving antenna. The penetration depth and the resolution depend on the electromagnetic properties of the materials through which the electromagnetic waves propagate and on the type of antenna that is used. Therefore, underground wave propagation decreases as the conductivity of the terrain or the frequency of the emitted signal increases (Rey et al., 2013). For a single profile, a higher carrier frequency of the antennas results in a higher resolution but also in a decreased penetration depth, and vice versa if the frequency decreases (Davis and Annan, 1989).

In this research, ground penetrating radar (GPR) with GSSI SIR System-20 was used to determine the shallow sedimentary strata from geomorphologic units that received from the aerial photos and satellite images interpretation. The GPR was set up with 200 MHz frequency antennas. The sections were corrected for topography where necessary. The table 4 below lists the appropriate antenna by application and depth range (Geophysical Survey Systems, 2009). Radar system takes readings (scans) at set 1 meter spacing.

The GRP equipment consists of MF-20 mainframe, laptop, mounting plate hardware, network shield and mainframe connector panel, the DC power adaptor, survey wheel and transmitter-receiver (orange box) in the Figure 29. GPR survey will be carried out in order to characterize reflection patterns and to assess the method's potential for image fluvial sediment as characteristic of radar facies. Then the data were interpreted the radar facies by comparing with previous work in fluvial environment. Representative samples of each locations were selected where the GPR data could be directly correlated with sedimentary information derived from exposures and detailed drilling, and geomorphological data could be supplied (Vandenberghe and van Overmeeren, 1999).

Table 4 Lists of the appropriate antenna by application and depth range. (Geophysical Survey Systems, 2009)

Frequency	Sample Applications	Typical Max Depth Feet (meters)	Typical Range (ns)
1.5 GHz	Structural Concrete, Roadways, Bridge Decks	1.5 (0.5)	10-15
1000 MHz	Concrete, Shallow Soils, Archaeology	3 (1)	10-20
400 MHz	Shallow Geology, Utility, Environmental, Archaeology	12 (4)	20-100
200 MHz	Geology, Environmental	25 (8)	70-300
100 MHz	Geology, Environmental	60 (20)	300-500

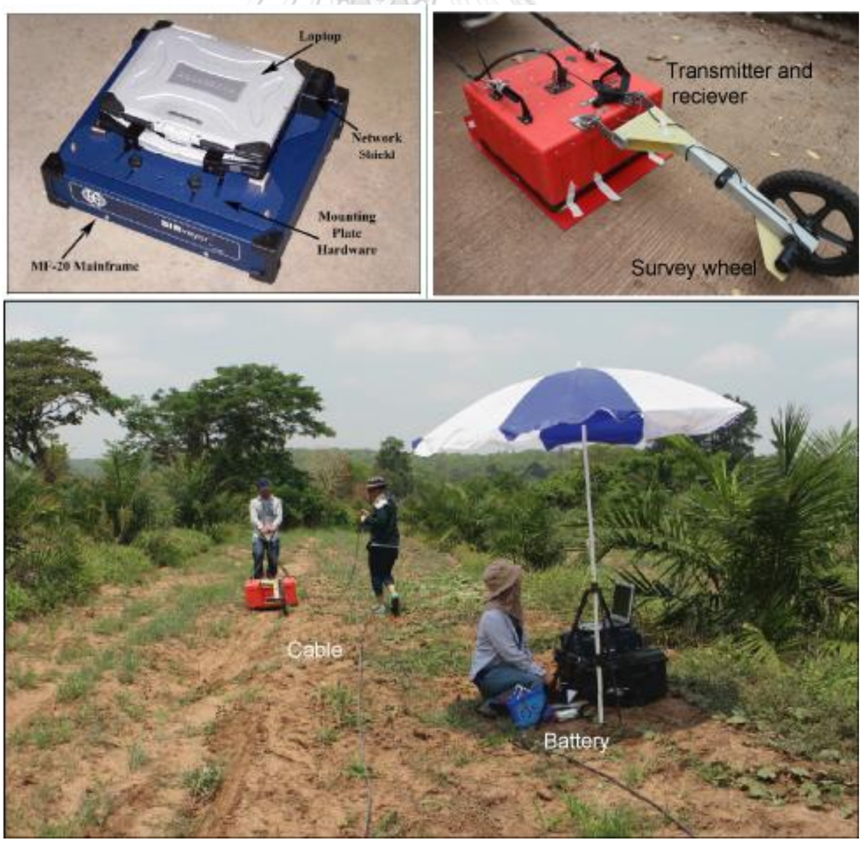


Figure 29 GPR acquisition and survey equipments.

3.2.3.2 Electrical Resistivity Tomography survey

The ERT method is the most popular technique to measure the subsurface resistivity. The conventional resistivity sounding is carried out on the earth’s surface with a specified array of electrodes in order to obtain apparent resistivity data with respect to the variation of horizontal position and vertical depth. Typically, the apparent resistivity distribution is presented in a pseudo section using computer software, hence an inversion process is essential in order to determine the actual resistivity of the subsurface (Wahida et al., 2015). The purpose is to measure the resistivity exhibited by a material when some electric current passes through it. This technique is thus one of the most efficient, non-destructive methods that can be used to study and characterize subsurface discontinuities (Rey et al., 2013). The method consists of placing electrodes along profiles using 1m and 5m electrode spacing that depends on the required resolution, depth and the purposes of the study. A higher resolution is obtained if the electrodes are placed closer, while for wider-spaced electrodes, a greater depth can be scanned (Rey et al., 2013).The electrical resistivity imaging survey carried out using dipole–dipole electrode arrays that are spread across the surface (Figure 30). The advantages of dipole-dipole configuration were used using short electrical line and sensitive to vertical change, so the paleo-channel geometry can be distinguished (Okpoli, 2013).

This method was considered the contrasting conductivity of the floodplain and in-channel sediments with different porosity and grain size characteristics. The equipment of resistivity survey includes resistivity meter (IRIS-SYSCAL R-1 Plus), metal probes, electric wires, hammer and direct battery (Figure 31). The metal probes can be divided in to 2 type as current and voltage probes. These probes were inserted into the ground to obtain a reading of the local electrical resistance. The current probes are used to introduce a current (either direct or low-frequency alternating current) into the earth while the voltage or potential probes are used to measure the voltage, which indicates the local resistivity.

The resistivity profiles have been interpreted based on the apparent resistivity obtained during fieldwork and processed with RES2DINV special resistivity and induced polarization software. This program uses the conditioned least squares smoothing method. The inversion procedure creates an underground model using rectangular prisms and determines the values of resistivity for each of these prisms, minimizing the difference between the values of the apparent resistivity that are observed and calculated (Wahida et al., 2015).

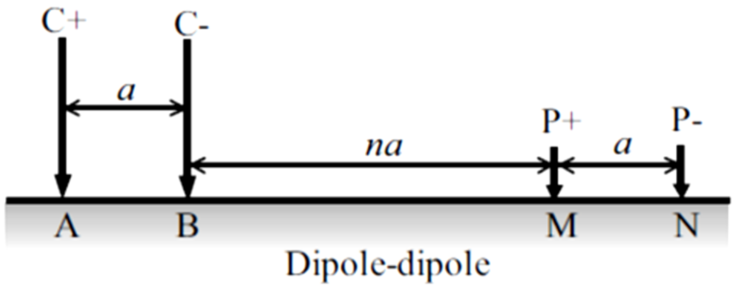


Figure 30 Dipole-dipole configuration (Wahida et al., 2015).

Figure 31 Equipment for two-dimension resistivity survey.

3.3 Laboratory analysis

As for laboratory analysis was sedimentary laboratory which conducted on the sediment samples from borehole for grain size analysis using laser particle size analysis.

3.3.1 Sedimentary Laboratory

All samples were photographed and described the lithology. The samples for grain size analysis were picked from each sediment layer which was distinguished the color, texture and composition by naked eyes. The purpose of measuring grain-size distribution is not only to classify sediment size, but also the lithological logs from boreholes were used to verify and interpret the lithologic types and boundary of GPR and ERT profiles. The sediment samples were analyzed by laser particle size analyzer. Samples were subsequently classified under the Sheppard's classification system for sand, silt and clay for distinguishing the sedimentary type (figure 32) (Folk, 1954, Pellicer and Gibson, 2011, Schlee, 1973). These lithological logs were scaled and superimposed on GPR and ERT profiles.

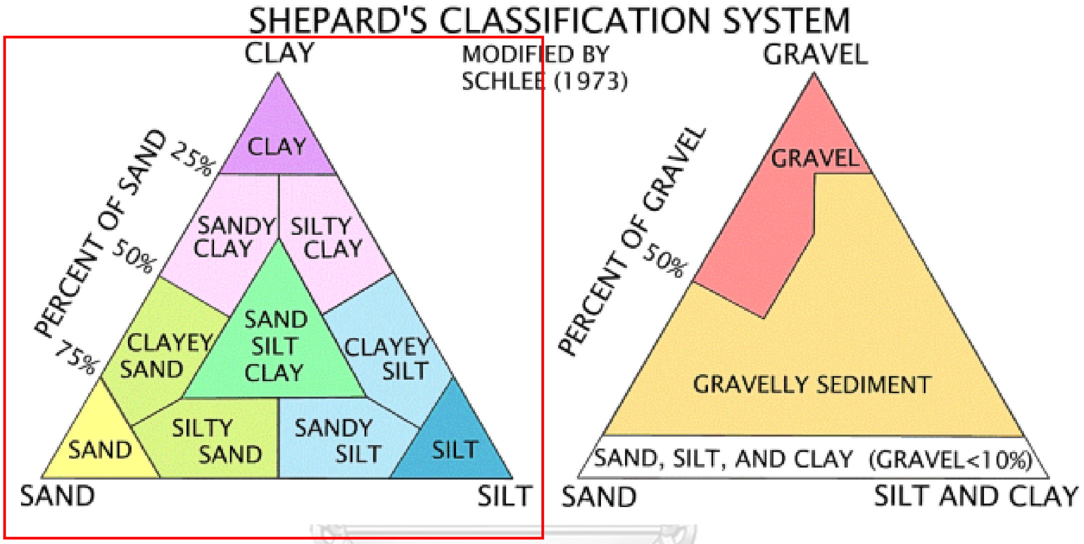


Figure 32 The proportions of silt, sand and clay of all samples after using grain size analysis method were classified by using Shepard's classification system for sand, silt and clay following any three component percentages to find the nominal name for the unconsolidated sediment type.

CHAPTER IV
Result of the study

Outcomes were divided in to six parts, they consists of office work, field investigation and laboratory analysis results. The first begins with the aerial photo interpretations from the aerial photographs and satellite image. The second part, geomorphic planform analysis results were displayed in terms of the sinuosity index, channel width, radius of curvature, migration rate and channel stability of the recent Mun River and paleo-channels. The third part, the longitudinal profile shows the topography of the study area. The fourth part, the geomorphologic field investigation was displayed the sedimentary stratigraphy and characteristic of sediment from each fluvial geomorphology from borehole along the geophysical survey lines and bank profiles. The fifth part, the sediment samples from borehole logs were analyzed by grain size analysis for identified the sediment properties. Finally, the results of subsurface sedimentary succession from shallow geophysical survey profiles (both of the GPR and ERT) were classified to radar facies by comparing with previous studies, and the resistivity data from inversion model were complemented with sedimentological data for identified apparent resistivity and classified Electrical Resistivity Tomography lithological classes (ERT class).

4.1 Result of aerial photograph & satellite image interpretation

The aerial photo interpretations using GIS software compared geomorphological changes from last four decades (1974, 1986 and 2011) especially in the upper part that connected to the Mun Bon Dam (upstream area).

Changing of geomorphology about 37 years (from 1974 to 2011) from aerial photos and satellite images can be observe by the migration and cut off of river channel to oxbow lakes and meander scars. These were interpreted for determined the effect on geomorphic landform.

The results from aerial photos scale range between 1:15,000 (1974) and 1:50,000 (1986), while satellite images (2011) scales of resolution more than 30 m for the most recent photo. From the oldest aerial photographs interpretation were taken in 1974 which was taken before the Mun Bon Dam construction (Figure 33). The Mun River flows in to the north direction, and it originates from the Sankamphaeng Ranges. As for the oxbow lakes, they mainly found in the upper part of the study area. The meandered scars (paleo-channels) display clearly on the both sides of the Mun River floodplain. The size of paleo-channels has variedly, and they can be distinguished into two types –medium and small paleo-channel groups. In some locaton, the paleo-channel showed the continuity of thread like a long river, but in some area displayed as an isolated paleo-channel. The analysis of size (channel width) and sinuosity index of paleo-channels were detailed in the geomorphic planform analysis part. As for Brice classification of meandering river, the Mun River in 1974 was classified as G1 Type which is two-phase bimodal bankfull, sinuosity, equiwidth in lower part of area. As for the upper part, the meander pattern was look liked B2 which has single phase, wider at bends and no bars.

Regarding to aerial photographs interpretation in 1986, the series of the pictures were limited in some part of the study, so it doesn't cover from the Mun Bon Dam (Figure 34). The Mun River flows in the same direction, and the channel size doesn't change from 1974. The oxbow lakes distributed mainly in the upper part of the study area. Regards meander scars were found in the same location as aerial photos in 1974, but it disconnected together because some meander scars disappeared.

Near present time of Mun River, the Satellite images in 2011 from were used. The geomorphological units distinguished as the present Mun River, oxbow lakes and meander scars (Figure 35). The oxbow lakes can be found in the upper part in Amphoe Chok Chai. As for meander scars were rarely to observe. The Mun River in 1986 was classified as B2 type which has single phase, wider at bends and no bars of Brice classification of meandering river. The Mun River in 2014 was classified from Brice classification of meandering river as B2 type which has single phase, wider at bends and no bars.

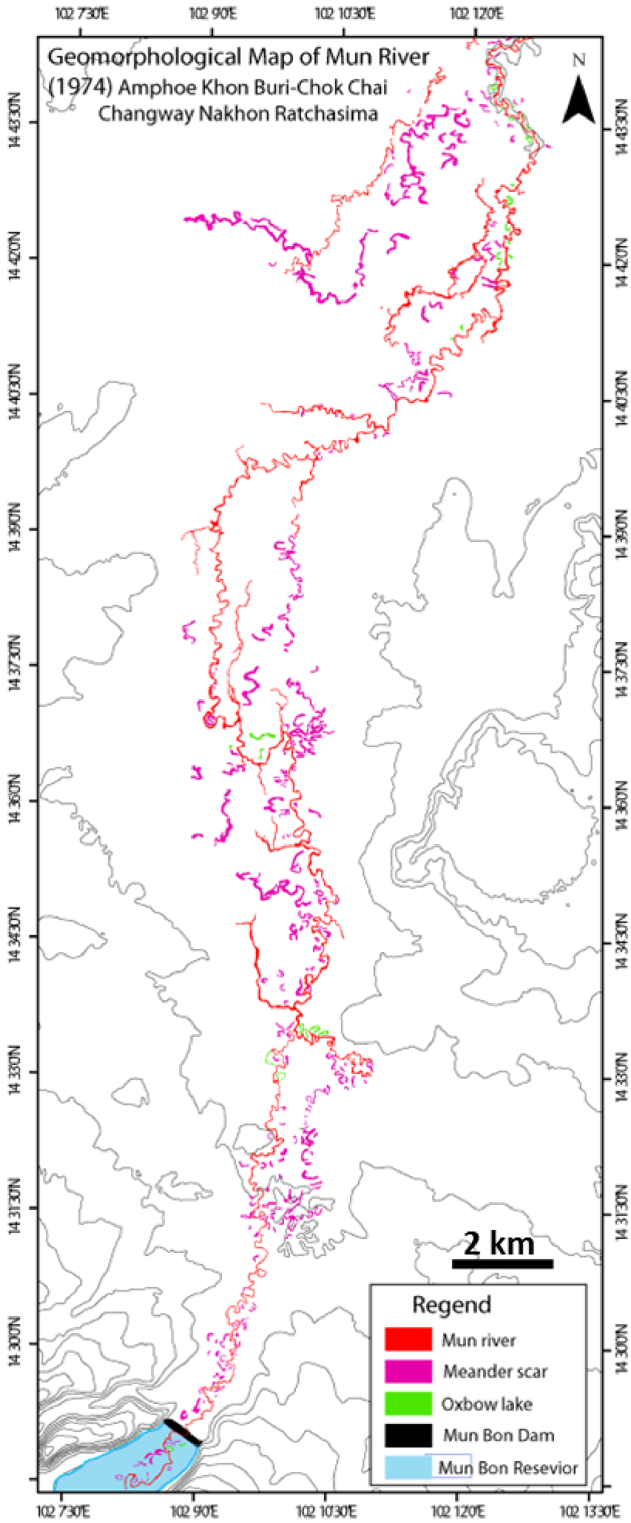


Figure 33 Result of aerial photo interpretation in 1974 (before Mun Bon Dam Construction), Plenty of meander scars found along both of river side. As for oxbow lake occur close to river, and it's usually found in the upper part of study area.

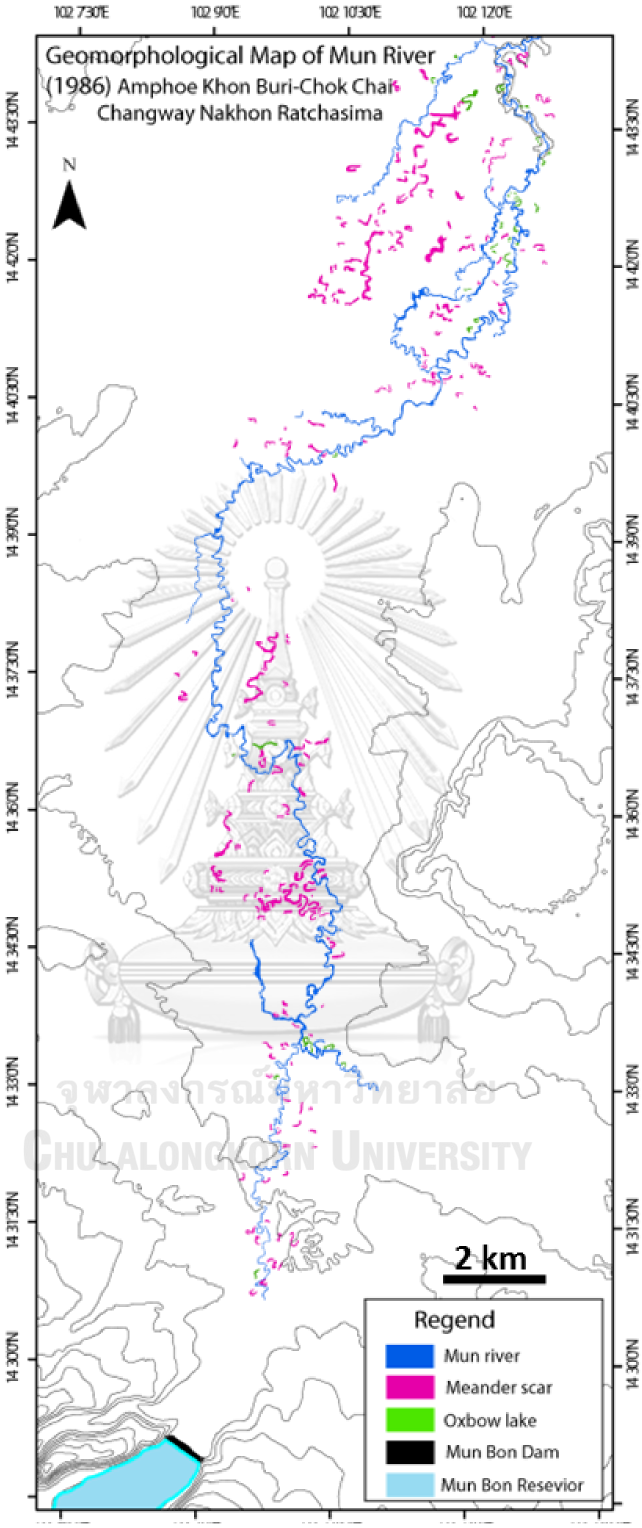


Figure 34 Result of aerial photo interpretation in 1986, the data limited by number of aerial photos. Meander scars existed along both of river side, but it changed from 1974.

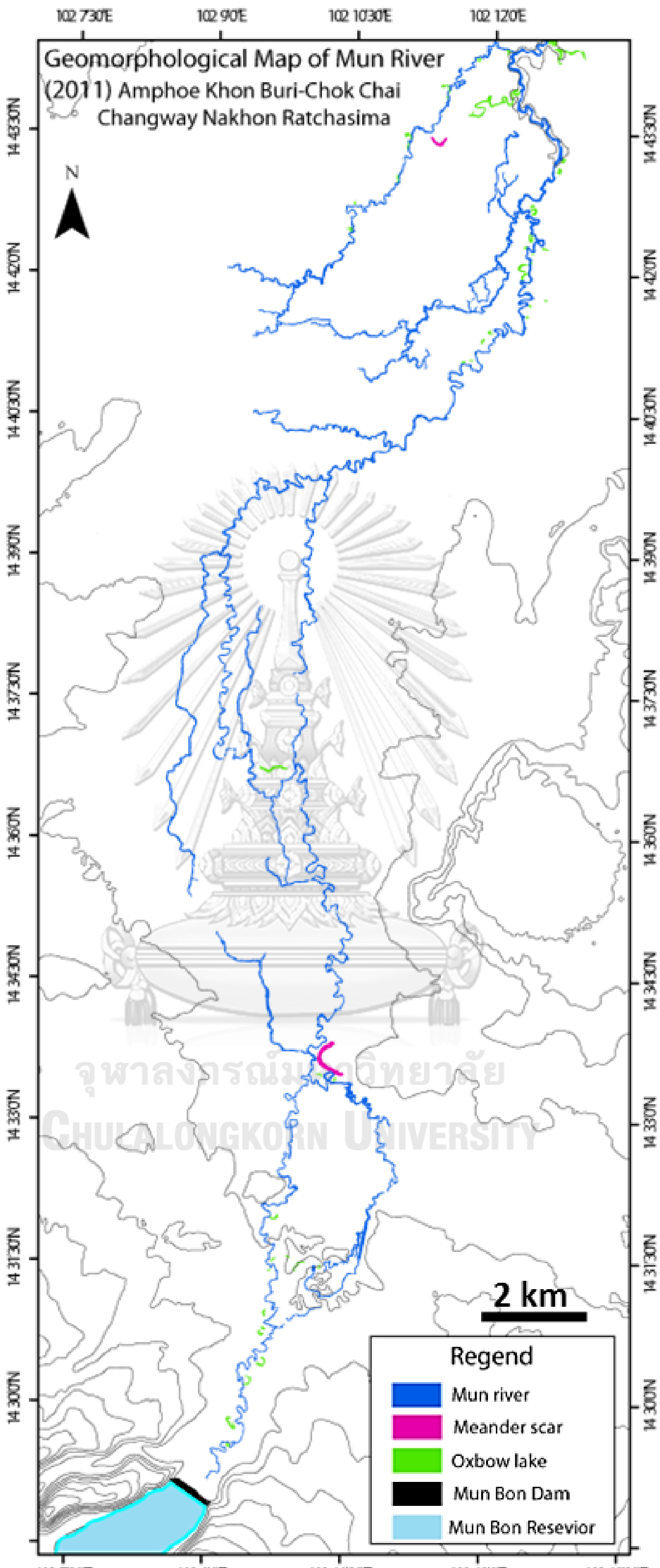


Figure 35 Result of satellite image interpretation in 2011, the river flow as same as recent time. Few meander scars and oxbow lake can observe along the river side.

4.1.1 Locating Paleo-Channel from Aerial Photographs

From the Mun Bon Dam to downstream, geomorphic units were classified from air-photos which were taken in 1974, 1986 and 2011. Each geomorphic unit is related to geologic setting with particular emphasis on meandering morphology. The geomorphologic map (scale 1:30,000) shows the detailed geomorphic changing from 5 reaches (1 to 5) (Figure 36). Change in morphology of the Mun River during 37 years can also be observed from a set of historical aerial photographs and satellite images taken in 1974 to 2011. Geomorphic parameters including river channels, oxbow lakes and meandered scars were compared in terms of width and locations from different periods of time. As a result, meandered scars were dominant.

A temporal change of channel migration can be observed from reach 1 (Figure 36 b and c) where the upstream part of the Mun River is located close to the Mun Bon Dam. Some channels were turned to meandered scars and sinuosity index was reduced from the past to present. Regarding to reach 2 and 3 (Figures 36 b and c), the process of channel migration occurred at the inner and outer bends where cut offs were dominant. The meandered scars were mainly recognized in the left side of the Mun River bank from reach 2. For reaches 4 and 5 (Figure 36 a), several meandered scars were larger than the size of the Mun River and distributed on the right side of floodplain (Figure 36 a). Direction of the Mun River (in 1974, 1986 and 2011) on the reach 5 flows follow same channel but it shifts gradually to the left side. Abandoned channel cannot be recognized from air-photo, only oxbow lakes that can be seen.

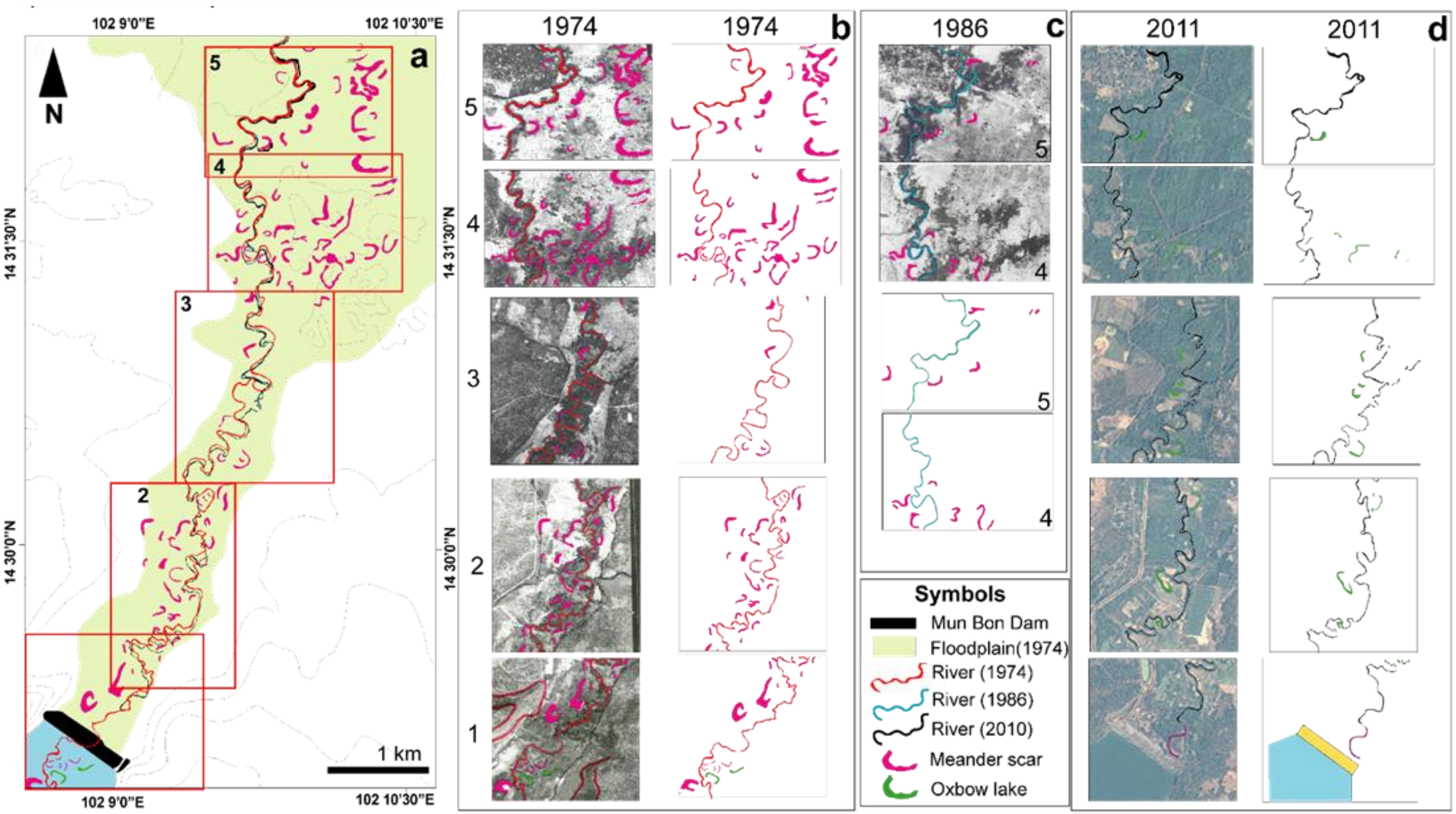


Figure 36 Comparison of geomorphic landforms interpreted from air-photos were taken in 1974, 1986 and THEOS1 image taken in 2011 in five river reaches. Meandered scars were dominant. Temporal change of channel migration was observed in the upstream part of the Mun River

4.2 Result of geomorphic analysis

As for geomorphic planform analysis, the geomorphic parameters of Mun River from recently time (2011) were compared in terms of sinuosity index and average recent channel width with paleo-channels (1974). Regards radius of curvature and channel migration rate of Mun River which were predicted the channel stability before (1974-1986) and after (2004-2015) the Mun Bon Dam construction was shown as the results.

4.2.1 Sinuosity index (SI) and channel width

The result shows the sinuosity index and channel width of the Mun River and paleo-channels. The study area was divided into ten reaches (Figure 37a and b). Two different sets of paleo-channels (medium and small-sized paleo-channel groups) which were measured channel width and compared with the recent Mun River.

The outcome of sinuosity index or meandering ratio (SI) and channel width was shown as Figure 37c. From the degree of meandering of river is defined by the sinuosity, all of the paleo-channel groups and recent river were classified as meandering river (Dey, 2014), and were categorized in meandering river which has SI between 1.5-2 (Hooke, 2007).

The average channel width of the medium sized, small sized abandoned channel and the recent Mun River are 35, 16 and 13 m, respectively. Size of recent channels is similar to small-sized paleo-channels. Trend of channel width was slightly increased especially from reach 5 to reach 8 (wider) from upstream (dam) to downstream of the recent Mun River. Size of medium-sized paleo-channels is varied (highly distribution). Small-sized paleo-channel width shows stability and slightly changed from 0 to 6 m. These river channels developed in the same geologic setting (on Khok Kruat formation) and low gradients of the terrain. Geomorphic analysis of Sinuosity Index and paleo-channel width of the Mun River was measured and plotted in forms of scattered graph for determining the relationships between group of different size paleo-channels and the recent Mun River existed in the same area

The comparison of SI among medium-sized abandoned channel, small-sized paleo-channel groups and the recent Mun River were shown in Figure 37 c. Most of SI was categorized as meandering river (Hooke 2007; Masalimova et al. 2015) with SI value between 1.5 to 2 (grey color in Fig. 37c top). The other zones display highly sinuous (>2) and sinuous zone (<1.5).

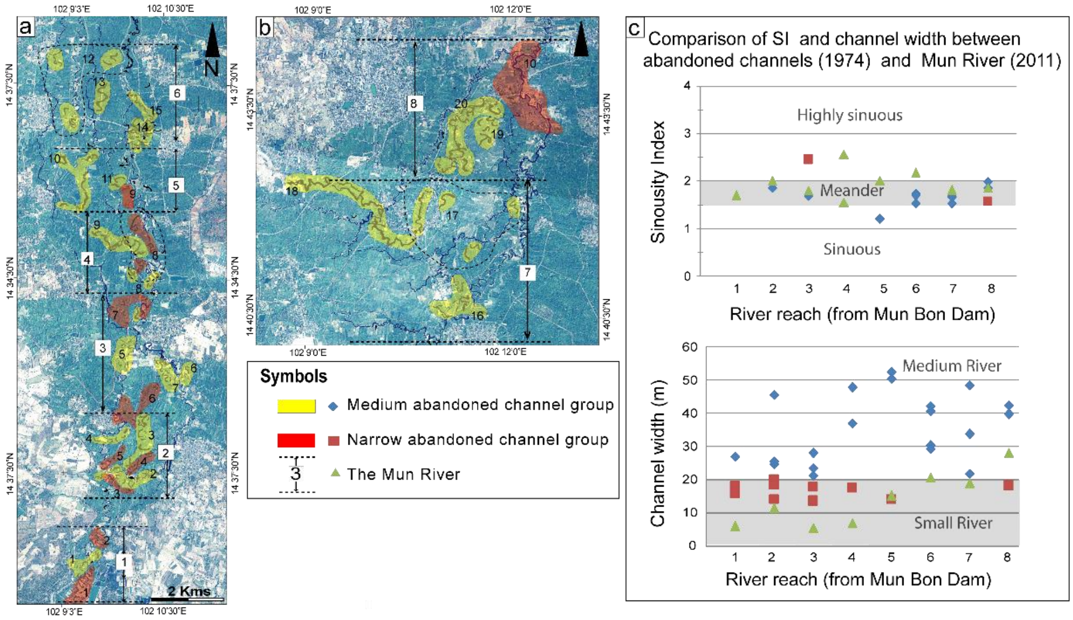


Figure 37 Location of paleo-channel group (A and B Channel width and SI of paleo-channel (1974) and recent Mun River (2011) from Mun Bon Dam to distributaries on low gradient plain is shown in scattered graphs (C). SI of all groups were classified as meandering river (> 1.5) (C (top)) (Nimnate et al., 2017).

4.2.2 Radius of Curvature (Rc)

Radius of curvature (Rc), channel width (W), meander migration rate per year (before and after the Mun Bon Dam construction) and meander migration rate versus bend curvature (Rc/W) or channel stability. The results of these planform parameters were calculated from ten randomed-reaches (Figure 38) which were measured from aerial photo (in 1974 and 1986) and satellite images from Google Earth (in 2004 and 2015).

As for the histogram of Radius of curvature, Rc has changed throughout ten locations (figure 39a). Low Rc and the river bend wide were depicted on the satellite image from locations 3 and 4. On the other hand, Rc in locations 9 and 10 shows high value and the river bend is tight., the Radius of curvature values seemingly indicated approximate values in the same location. From upstream to downstream, the radius of curvature fluctuated from location 1 to 10 and shown high Rc value in location 9 and

10. The lowest radius of curvature value found in location 4 (the Rc is 53.79 in 2015), and the highest Rc found in location 9 (the Rc is 204.3 in 1986).

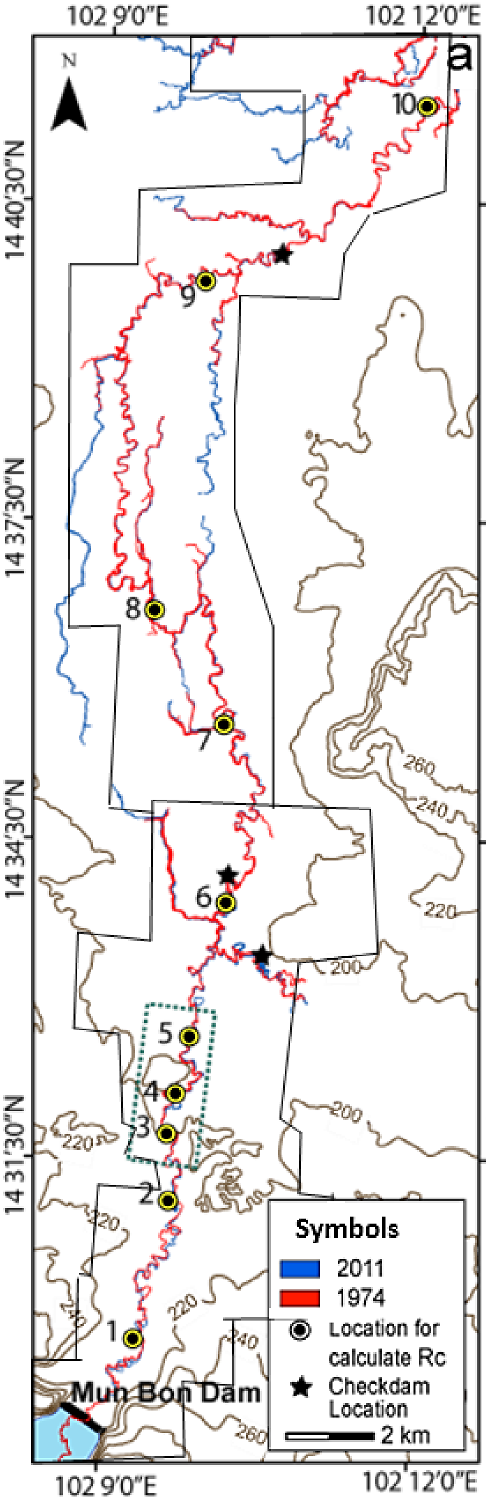


Figure 38 Locations for calculating for the Rc value in 1974 and 2011 and check dams along the Mun River (Nimnate et al., 2017).

4.2.3 Migration rate

The migration rate per year depicted the difference of distance of point bar area in a period of time. This process forms by the lateral migration of meander bends. Channel widths of the Mun River measured from photos in 1974, 1986, 2004 and 2015 were also compared. Lateral migration rate decreases after the Mun Bon Dam construction in locations 2, 6, 7, 8 and 9 (Figure 39 d)

4.2.4 Channel stability

As for channel stability evaluation which normally measured from historical aerial photographs in comparison with the modern channel. The relationship between radius of curvature values, channel width and meander migration rate provides information about the channel stability trends of four periods as 1974, 1986, 2004 and 2015 (Figure 39d).

For the channel width, at location 5, the river shows narrowest and decrease in channel bend and width comparing with the other location after Mun Bon Dam construction. The channel width varied from location to location. The location 1, 2, 3, 9 and 10, the channel widths are wider than the period before the dam construction, but the channel became narrower in the location 4 to 8 (Figure 39b). The meander migration rate per year before (1974 to 1986) and after (2004 to 2015) dam construction is shown in Figure 39c.

The radius of curvature of all periods was fluctuated. These indicate the variation of the channel stability in the past and in each location. Rc/W from 10 locations measured from 1974, 1986, 2004 and 2015 were plotted against the migration rate (Fig. 39d). Rc/W values can predict the behavior of river. Three main processes were categorized from graph based on Rc/W ratio including the occurrence of chute- or neck-cut offs (1 to 2), bank erosion (2.5 to 4) and zone of low erosion rate (>5) (Nanson and Hickin 1983). Result from air-photos interpretation from the years 1974, 1986, 2004 and 2015 within the study area shows low erosion rate with meander migration rate between 0.71 to 2.64 m/yr (Figure 39c and d).

In conclusion, the relationship between migration rate and bend curvature indicate that the Mun River can be categorized as low erosion rate river.

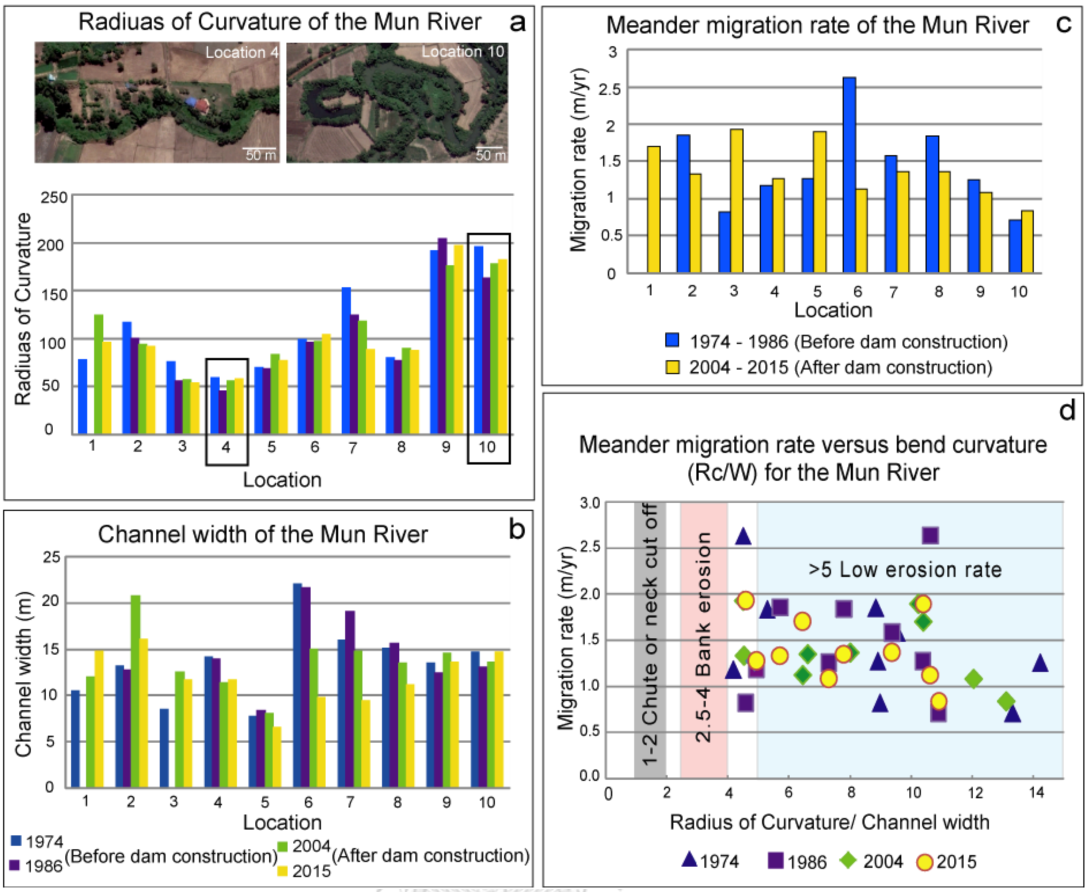


Figure 39 Graph a shows Rc trend in 1974, 1986, 2004 and 2015. Low and high value of Rc are shown in locations 4 and 10 on satellite images. Channel width measured from ten locations is shown in graph b. Meander migration rate before 1974 and after the Mun Bon Dam construction is shown in graph c. Meander migration rate versus bend curvature (Rc/W) for the Mun River exhibited in graph d. Most of the Mun River selected bends in ten zones were categorized in low erosion rate zone (light blue color) (Nimnate et al., 2017).

4.3 Longitudinal profile

A longitudinal profile is constructed from a total of 22 point-locations from the Mun Bon Dam to the Mun River distributaries (Figure 40). The topographic gradient from six segments exhibits approximately 1.86, 1.03, 1.10, 0.47, 0.93 to 0.44 m/km from the river of segments 1 to 6, respectively (Figure 40 top). These topographic gradients were slightly changed from dam area to low gradient plain making the study area becomes very low gradient topography. The Mun River flows on gradually and slightly inclined plane to the Khorat Basin in the north direction. The point elevations range between 212.62 m and 184.67 m above msl.

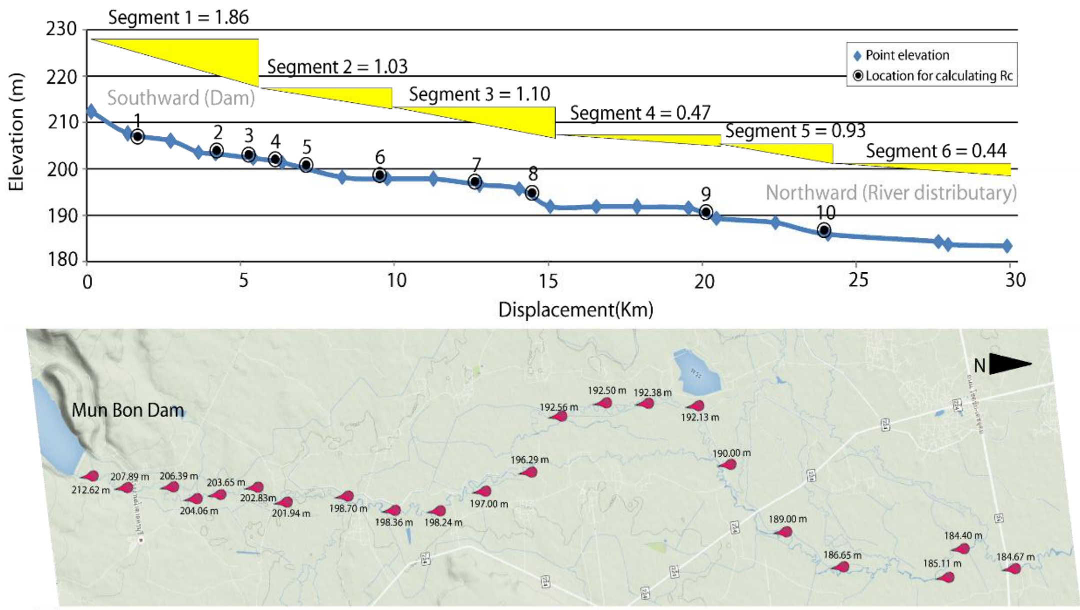


Figure 40 Longitudinal profile extending from the Mun Bon Dam to the Mun River distributaries was plotted from 22 point-elevations along the river which gradually inclines to the Khorat basin in the north. Six segments of gradient calculated from vertical distance divided by horizontal distance. Slopes slightly change from dam to river distributaries from 1.86, 1.03, 1.10, 0.47, 0.93 to 0.44 m/km. (Nimnate et al., 2017)

4.4 The result of fluvial sediments description

Sedimentological investigation was carried out on each geomorphic unit nearest to the survey line using a hand auger and percussion drilling from each geomorphic unit. The lithological logs from boreholes were used to verify the lithologic types and boundary of GPR and ERT profiles. The main target of borehole drilling is paleo-channel, floodplain and point bar location. Moreover, the present river bank is also the target for study present meandering river process. The sediment samples from borehole and river banks were analyzed by laser particle size analyzer. Samples were subsequently classified under the Sheppard's classification system for sand, silt and clay for distinguishing the sedimentary type (Flemming, 2000, Folk, 1954, Pellicer and Gibson, 2011, Schlee, 1973).

4.4.1 Sedimentological data from Boreholes

The physical characteristics of sediments were illustrated as figures with detailed of lithological description. The sediment samplings were collected from each morphological feature which appears in the study area as the paleo-channel, point bar, floodplain and river bank, and the locations were displayed on sediment sampling location map in Figure 41 The vertical variation in sediment samples were collected from each geomorphological unit by hand auger and percussion coring to compared with geophysical survey in the same area. Moreover, observing for sediment succession at bank profiles is complementary to modern fluvial succession.

As for boreholes, the 15 cores were collected in point bar, meander scars (paleo-channels), outer bank and floodplain from eight sites. The depth of penetration for collecting sediment is deeper than using aluminum cores. The sediment core figures show in the appendix. Moreover, two banks profiles were surveyed. Sample from hand auger were logged in the field and were picked from the same layer until it changed to another layer and installed it in zip-lock plastic bag brought back to the laboratory.

For grain size analysis, sediment sample from nine boreholes from three locations (location 1, 4, and 5) were chosen as the representative sample of point bar, paleo-channel and floodplain along the ERT and GPR line. These data were applied for compare the relationships between sediment size and shallow geophysical field survey.

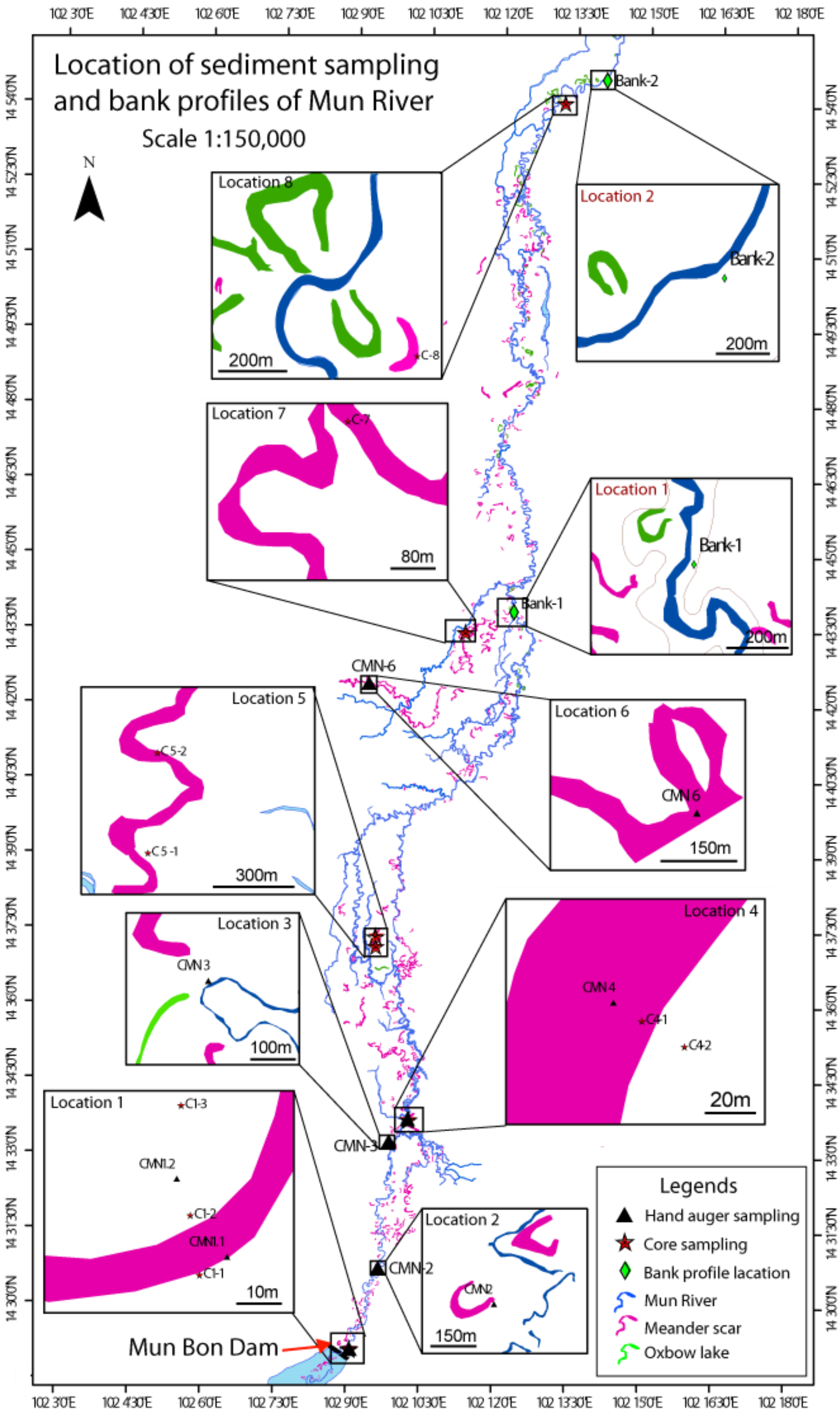


Figure 41 This map shows location of sediment sampling by hand auger, percussion coring and bank profiles in the study area.

1) Location 1 : Paleo-channel and point bar (Near the Mun Bon Dam)

The result of logging sediment layer by using sediment size, color and texture characteristics were conducted and illustrated as figures. As for location 1, two cores (CMN 1.1 and CMN 1.2) and three bore holes (C1-1, C1-2 and C1-3) drilled by percussion and hand auger. This site located connected to the Mun Bon Dam.

The location of CMN 1.1 at old channel is located at latitude 14.48524 degree and longitude 102.151433 degree. The total depth of the core is the 130 cm. It can be divided into 9 layers. The sediment layers mainly composed of sand interbedded with mud and found some peat layers.

The location of CMN 1.2 at point bar of the Mun River is located at latitude 14.485392 degree and longitude 102.151329 degree. The total depth of the core is the 220 cm. It can be divided into 7 layers. The sediment layers mainly composed of sand interbedded with mud and found some peat layers. The sediment layers mainly composed of very fine sand.

The location of C1-1 at the bank of old channel of the Mun River is located at latitude 14.485203 degree and longitude 102.151378 degree. The total depth of the core is the 400 cm. It can be divided into 10 layers. The sediment layers mainly composed clay interbedded with sand.

The location of C1-2 is located at latitude 14.48532 degree and longitude 102.151358 degree. The total depth of the core is the 400 cm. It can be divided into 9 layers. The sediment core was drilled from point bar. The sediment layers mainly composed medium to fine sand.

The location of C1-3 is located at latitude 14.485537 degree and longitude 102.151336 degree. The total depth of the core is the 400 cm. It can be divided into 8 layers. The sediment core was gathered from point bar. The sediment layers is mainly composed of sand.

2) Location 2 : Floodplain connected with meander scars (Ban Mai Mun Bon)

As for location 2, one core (CMN 2) drilled by percussion. This site located connected in Ban Mai Mun Bon Village. The location of CMN at floodplain connected with meander scars in Ban Mai Mun Bon is located at latitude 14.512531 degree and longitude 102.160911 degree. The total depth of the core is the 145 cm. It can be divided into 3 layers. The top soil is mainly composed of silt and clay, and it is underlain by fine sand.

3) Location 3 : Concave bank of the Mun River (Ban Sa Phak Pot)

As for location 3, one core (CMN 3) drilled by percussion. This site located connected in Sa Phak Pot Village. The location of CMN 3 was drilled at concave bank from the recent Mun River (latitude 14.554677 degree and longitude 102.164156 degree). The total depth of the core is the 195 cm. It can be divided into 4 layers. The sediment succession is mainly composed of silt

4) Location 4 : Paleo-channel and point bar (Ban Nong Suea Bong)

The forth location surveyed on paleo-channel and point bar at Ban Naog Suea Bong which is far from the Mun Bon Dam approximately 9 kilometers. One core (CMN 4) and two bore holes (C4-1 and C4-2) were drilled by percussion and hand auger. This site located connected to the Mun Bon Dam.

The location of CMN 4 is located at latitude 14.561953 degree and longitude 102.170507 degree. The total depth of the core is the 155 cm. It can be divided into 3 layers. The sediment from paleo-channel in Nong Suea Bong Village, the upper part is dark sandy clay, and the lower part is greyish medium to coarse sand.

The location of C4-1 is located at latitude 14.561882 degree and longitude 102.17062 degree. The total depth of the core is the 230 cm. It can be divided into 4 layers. The sediment core was drilled from paleo-channel in Nong Suea Bong Village. The sediment collected from the ridge of rice field. The upper part is brown, but I the lower part turn to clay. The sediment layers are mixed up with sand and clay.

The location of C4-2 is located at latitude 14.561784 degree and longitude 102.170788 degree. The total depth of the core is the 240 cm. It can be divided into 4 layers. The sediment core from point bar near paleo-channel. The sediment layers are mixed of sand and clay.

5) Location 5 : Paleo-channel and floodplain (Ban Wang Tabaek)

Paleo-channel and point bar sediments at Ban Wang Tabaek were collected two bore holes (C5-1 and C5-2) by hand auger. The location of C5-1 is located at latitude 14.619496 degree and longitude 102.158743 degree. The total depth of the core is the 250 cm. The sediment core from floodplain was collected from the rice field. The sediment grain sizes mainly compose of silty clay and clay size, and it has been divided in to 6 layers.

The location of C5-2 is located at latitude 14.622922 degree and longitude 102.159024 degree. The total depth of the core is the 300 cm. It can be divided into 6 layers. The floodplain sediment was undertaken in the rice field. The upper part of the bore hole, sediment grain size mainly composes of silty to sandy clay (0-190 cm), and the lower part are mainly composed of fined to medium sand (191-250 cm).

6) Location 6 : Bank of Paleo-channel (Ban Phlapphla)

Outer bank of paleo-channel from eastern side of the Mun River which showed the river trace that have flowed parallel to Lam Sai, and jointed to the Mun River at Ban Phlapphla. The samples were collect by percussion drilling. The location of CMN6 is located at latitude 14.707199 degree and longitude 102.155458 degree. The total depth of the core is the 200 cm. It can be divided into 5 layers. At the upper part of the bore hole, sediments are mainly composed of silt and clay with very dark grey color of topsoil (0-7 cm). From the depth of 8 to 50 cm, silty clay is dominated, and it shows dark grey color with brown mottle (5%). Then the middle layer is mainly composed of clay in brown color with 50% mottles (101-173 cm). The bottom layer from 174 to 200 cm depth found medium to fine sand with 70-80% dark brown mottles.

7) Location 7 : Paleo-channel (Wat Bot Khongkhla Lom)

Paleo-channel sediments at Wat Bot Khongkhla Lom area was collected one bore holes (C7-1) by hand auger. The location of C7-1 is located at latitude 14.724327 degree and longitude 102.188329 degree. The total depth of the core is the 400 cm. The sediments can divide in to 8 layers. From the surface to 30 cm is brown to reddish brown top soil. The middle part from 31 to 300 cm mainly consists of clay and clayey sand in yellowish brown to brown color. The lower part is associated with sandy clay and clayey sand.

8) Location 8 : Meandered scar of the recent Mun River (Ban Khi Tun)

Meandered scar location is near the oxbow lake and the Mun River at Ban Khi Tun. This meandered scar cut off from the Mun River. Bore holes (C8-1) drilling by hand auger is located at latitude 14.900941 degree and longitude 102.22058 degree. The total depth of the core is the 300 cm. The sediment can be divided in to 6 layers. From the surface to 50 cm is dark brown with Fe-oxide disseminated spots of top soil.

The middle part mainly consists of clay and silty clay in yellowish to greyish brown from 50 to 110 cm. The bottom part is associated with fine to medium sand in grey color from 241 to 300 cm.

4.4.2 River Bank profiles

The present fluvial sediment succession was examined along the bank of the Mun River from Ban Nong Khla (Figure 42) and Ban Khi Tun area (figure 43). The bank slope faces were trenched to get fresh exposures for better identification. The detailed descriptions of the bank stratigraphy were made at each site, and it is explained as follows.

1) Location of Bank 1 : Ban Nong Khla

The bank profile 1 of Mun River at Ban Nong Khla is located at latitude 14.731285 and longitude 102.205 degree. The bank sediment was conducted on the stratigraphy and the samples were collected for grain size analysis. The height of the river bank is approximately 4 meters (Figures 42). The Mun River is 12-meter wide. The high of section is 3.3 meters. The upper most layer is topsoil which mainly consist of brown clay and silt from surface to 170 cm. The second layer is brown clay with iron concretion (approximately 1%). The bottom layer is greyish clay with 1 to 2 cm of 5% iron concretion which shape rounded to well rounded (Figures 42 a and b).

2) Location of Bank 2 : Ban Khi Tun

As for bank profile 2 (outer bank) of Mun River at Ban Khi Tun were examined the sediment succession and collected the bank sediments every 10 centimeter. The profiles have divided in to two sections; upper (red rectangular) and lower (yellow rectangular). The sampling site is located at 14.908647 and longitude 102.234841. Entire section is 4 meter-height, and the detailed of sediment shows in (Figure 43). The upper section can be divided in to three layers from top to bottom. The first layer (0 t0 90 cm) consists of brown silt to very fine sand with orange mottles and found some rootlets. This layer shows coarsening upward sequence. Next layer continued from 91 to 140 cm which mainly compose of silt with brown color, and this layer found peat fragments (Figure 43 a). Moreover, in this layer found peat fragment (size between 1 to 10 mm) and it orientation dipping to channel direction. Animal burrow appeared at 160 cm depth, and it can classified as crane fly larva burrow (James and Dalrymple, 2010). The size of crane fly larva burrow is approximately 20 cm long and 5 cm wide, and it was filled with sediment (Figure 44). The bottom from 141 to 200 cm, the sediment is finer than the other two, and it is light grayish brown clay and silt with some animal burrows. Regarding lower section, from the depth 200 to 250 centimeter is mainly compost of weathered maroon siltstone with some iron concretion and brown fine to medium sandstone. The next layer from 250 to 330 cm, siltstone to very fine sandstone is maroon color and found some calcareous vain (diameter 1-2 mm) and iron concretion approximately 2 percent (Figure 43b). The bottom layer found at 331 to 400 cm which consists of maroon siltstone to very fine sandstone with some calcareous vain intercalated (Figure 43c) in this layer (size of vain is about 1-7 mm; white color).

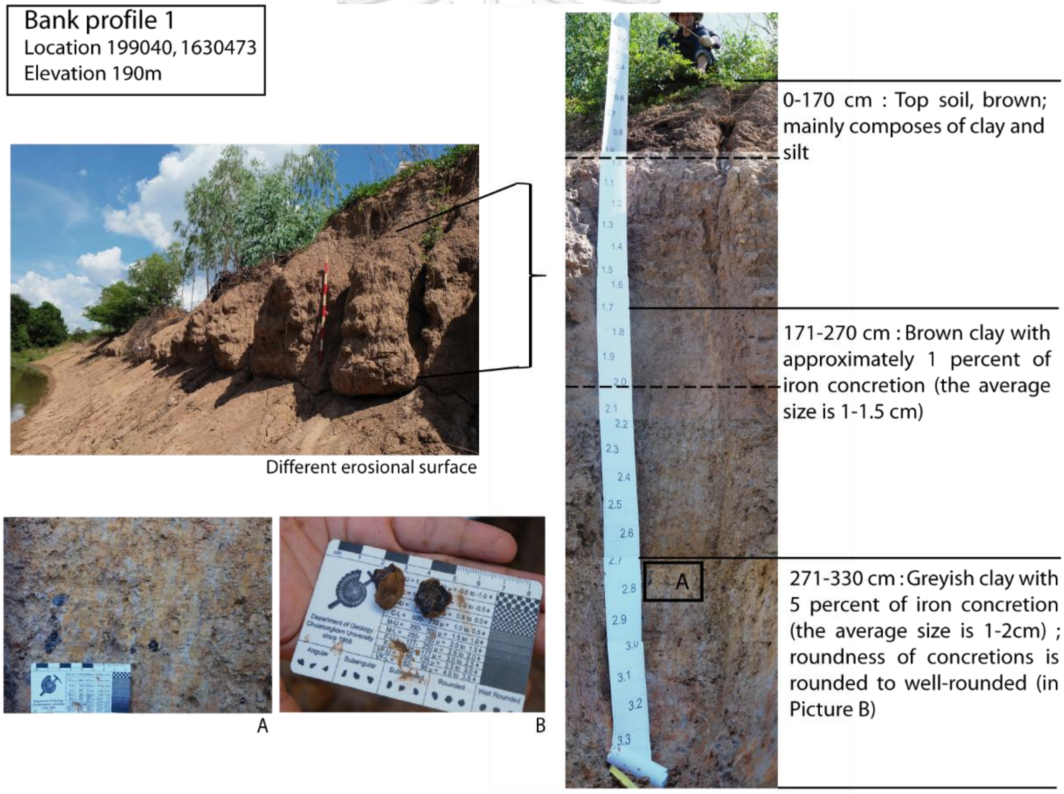


Figure 42 The location of bank profile conducted on the Mun River bank at Ban Nong Khla. The bank high is approximately 3 m, and It can be divided in to three layers. Clay is the minor composition of river bank. Moreover, iron concretions were found at the bottom part.

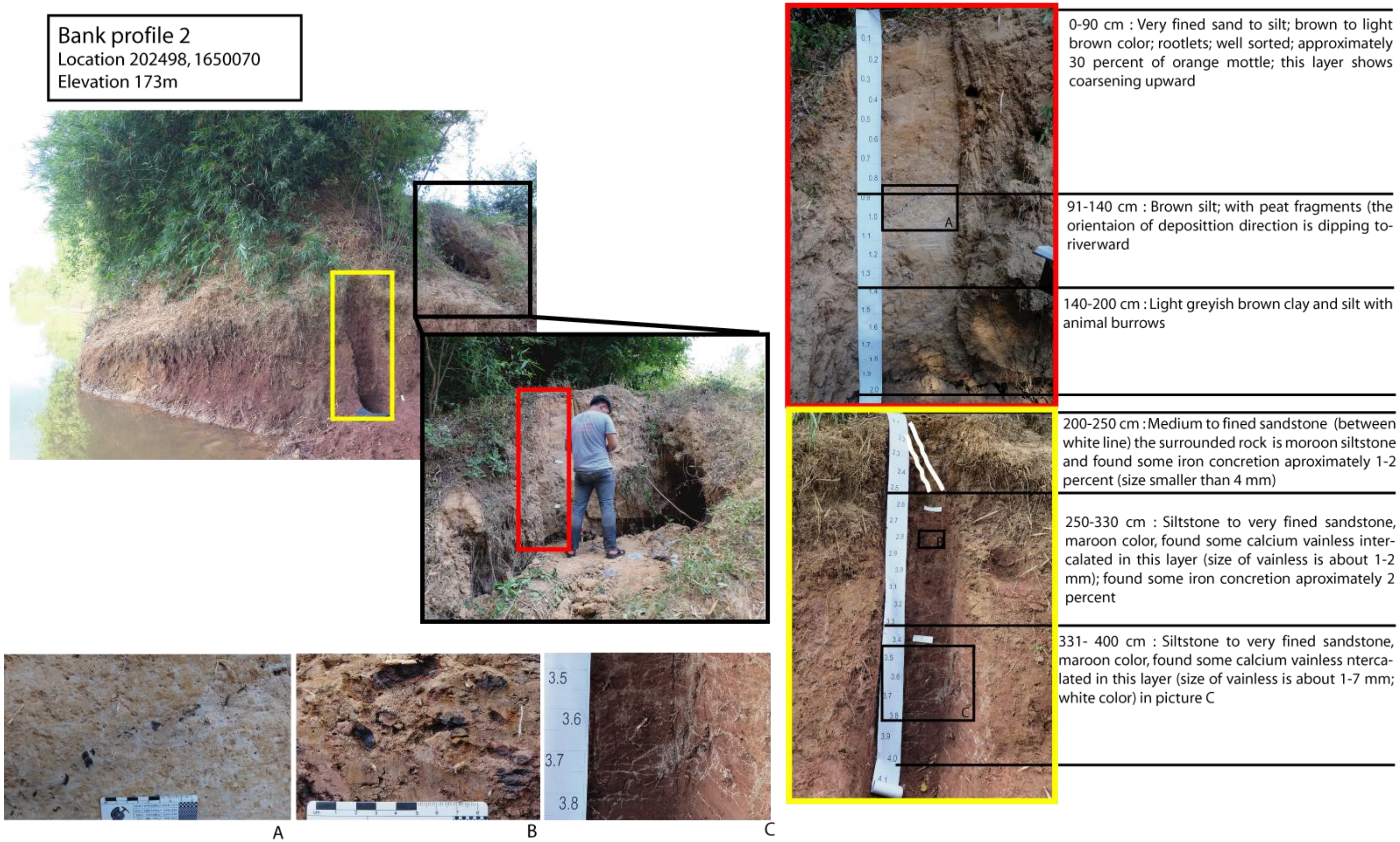


Figure 43 At Bat Khi Tun area, the detailed of bank profile survey along the Mun River's bank. The bank high is approximately 4m.

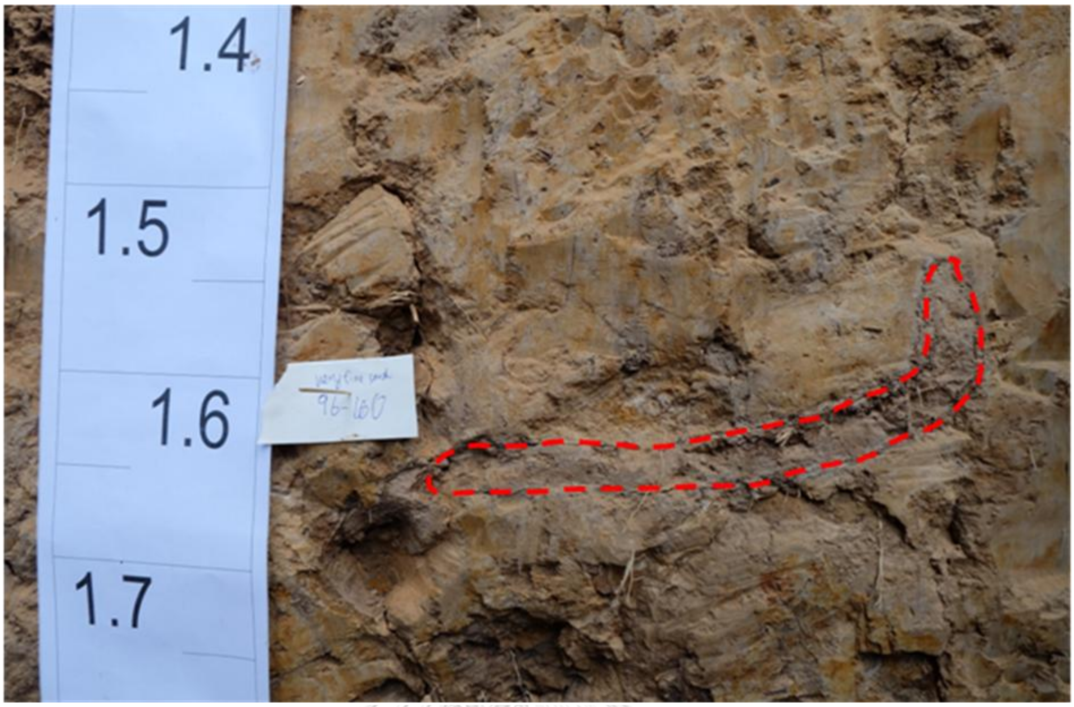


Figure 44 Animal burrow (Crane fly larva burrow) at 160 cm depth in the upper part of bank profile 2 (James and Dalrymple, 2010)

4.4.3 Result from Grain Size analysis

The sediment samples were examined in the detailed of lithology of sediments that were drilled by hang auger from borehole. The samples were picked from each different sediment layers from nine boreholes along the effective shallow geophysical lines from three locations (location 1, 4 and 5). The grain sizes of sediments were measured, and also the detail of sediment type from boreholes were used to verify and interpret the subsurface sediment and boundary of GPR and ERT profiles. Based on the Sheppard's classification system for sand, silt and clay (Flemming, 2000, Folk, 1954, Pellicer and Gibson, 2011, Schlee, 1973), the sediment samples were classified and make the lithological logs.

Characterizations of nine boreholes are based on laser particle size analyzer from 51 samples, and the proportions of sand silt and clay were classified under the Shepard's classification system modified by (Figure 45). Boreholes C1-1, CMN1, C1-2 and C1-3 are located on location 1 (Near Mun Bon Dam). Boreholes CMN4, C4-1 and C4-2 are drilled on location 4 (Ban Nong Sua Bong). Boreholes C5-1 and C5-2 are gathered from location 5 (Ban Wang Tabaek).

Sediment cores from location 1 were drilled on the dried channel (CMN1) and point bar (C1-1, C1-2 and C1-3). In general, on point bar deposit, C1-1 and C1-2 boreholes are dominated by silty sand, loam, clayey sand, and sand, while C1-3 core is dominated by loam in the upper part. The lower part is composed of sandy clay, silty sand and clayey silt. However, CMN1 is composed of sandy to silty clay and silty sand from dried channel location.

From sedimentological data from Ban Nong Sue Bong (location 4), three boreholes were drilled from paleo-channel. CMN4 was collected the sediment from rice field. It is composed of sandy clay and clayey sand. CMN4, C4-1 and C4-2 are dominated by loam and clayey sand with some iron concretion-baring in loam layer from the 1.4 to 2.3 meter-depth.

Two boreholes were gathered from floodplain (C5-1) and paleo-channel (C5-2) at Ban Wang Tabaek (location 5). Based on the sedimentary log from floodplain location, the finer sediment that is dominated by clayey silt with loam and silty clay in C5-1. On the other hand, C5-2 is mainly composed of coarser sediment as sand (clayey to silty sand) and silt (clayey to sandy silt) and loam from the paleo-channel's location.

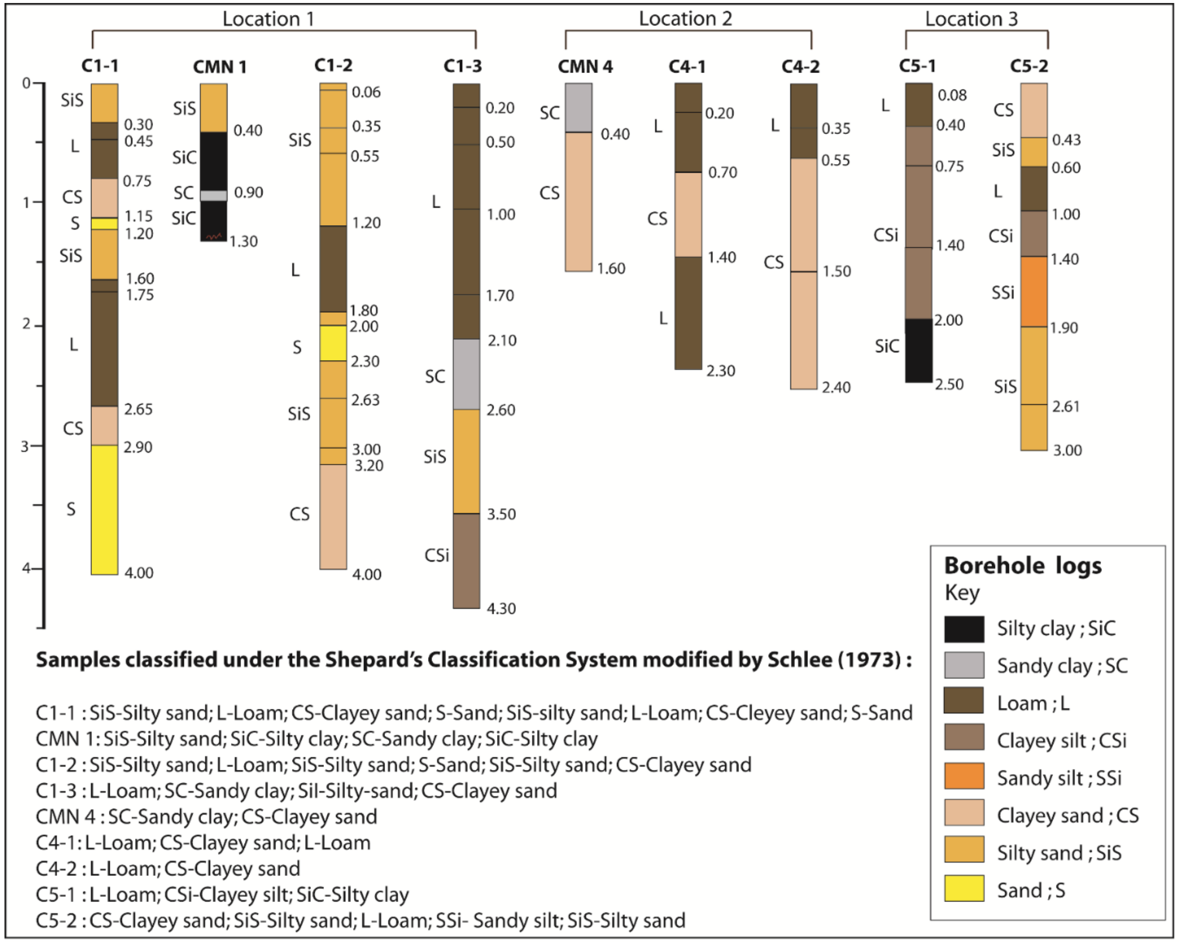


Figure 45 Detailed sediment logs from 3 locations (location 1, 4 and 5). The sediment from each layer was analyzed by laser particle size analysis and were classified from the percentage of sand, silt and clay particle.

4.5 Result of Geophysical Survey

Shallow geophysical surveys, both of ground penetrating radar (GPR) and Results of Electrical Resistivity Tomography (ERT) Survey were conducted to obtain shallow subsurface stratigraphy (approximate depth to 5-20 m) on eight sites along the Mun River in the Figures 46 and 47). The subsurface stratigraphy can be confirmed relationships between geomorphologic and lithological data that may lead to understand the fluvial succession in the past. The history of avulsions of river was revealed from occurrence of paleo-channels, so the main target of geophysical survey is meander scars especially Results of Electrical Resistivity Tomography (ERT) Survey. The GPR survey is focusing on the sedimentary succession in recent periods as point bar because this method is unsuitable for clay deposit.

Figure 46 Field investigation locations of Ground Penetrating Radar (GPR) (Location 1 and 2) and Electrical Resistivity Survey (ERT) (Location 1-6) at 1: Near the Mun Bon Dam, 2 : Ban Nong Sano, 3 : Ban Nong Sua Bong, 4 : Ban Muang Tako, 5 : Ban Mai Don Ket and 6 : Ban Wang Tabeak.

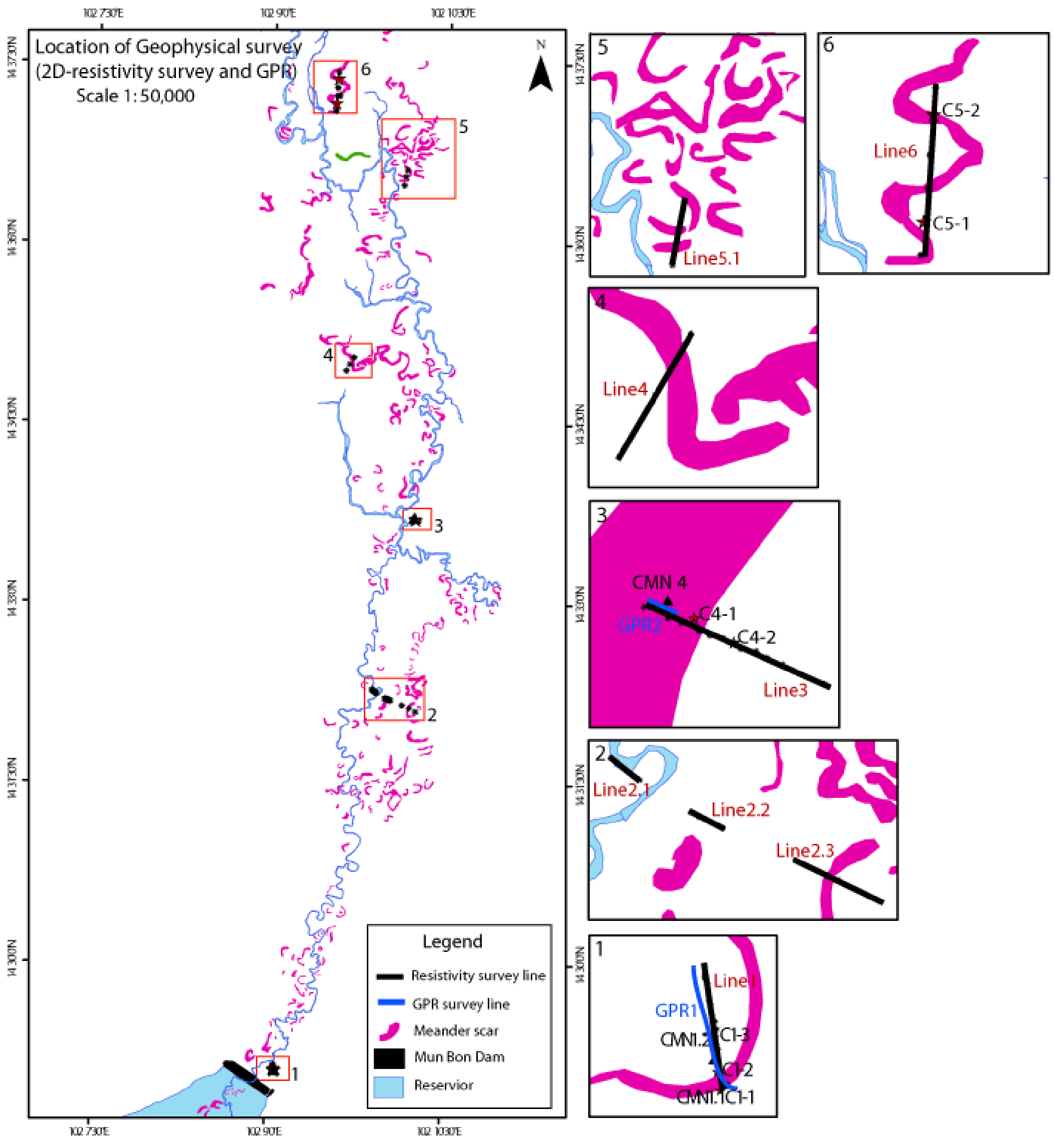


Figure 47 This map shows locations of eight sites of electrical resistivity tomography and two sites of ground penetrating radar survey along the Mun River. The meander scars are the main target of resistivity survey. As for GPR, recent deposit as point bar is aim.

4.5.1 Ground Penetrating Radar

Locations and direction of GPR profiles are illustrated in Figs.47 (Location 1 and 3). Location 1 is located Near the Mun Bon Dam which surveyed on point bar and paleo-channel. Based on the Location 3 at Ban Nong Sua Bong, the main targets of the investigation are paleo-channel and floodplain.

1) Location 1: Near the Mun Bon Dam

GPR result from location 1 surveyed on the dried channel and point bar almost NS direction120 m (Figure 48) shows a maximum depth of 4.40 m. Three different zones can be distinguished depending on the contrast of GPR signal. Uppermost zone of GPR profile presents obscure radar reflection, whereas the faded parallel can be observed from the upper part. Low angle dipping reflection (10° to 45°) from surface of silty sand and loam layers show inclination and discontinuous reflection pattern between 1.5 to 2.5 m in the middle zone. Sediment layer dips eastward into the dried channel. The lower zone of profile displays poor reflectivity because sediment layer cannot be observed from water saturated silt and sand from 2.5 to the deeper area.

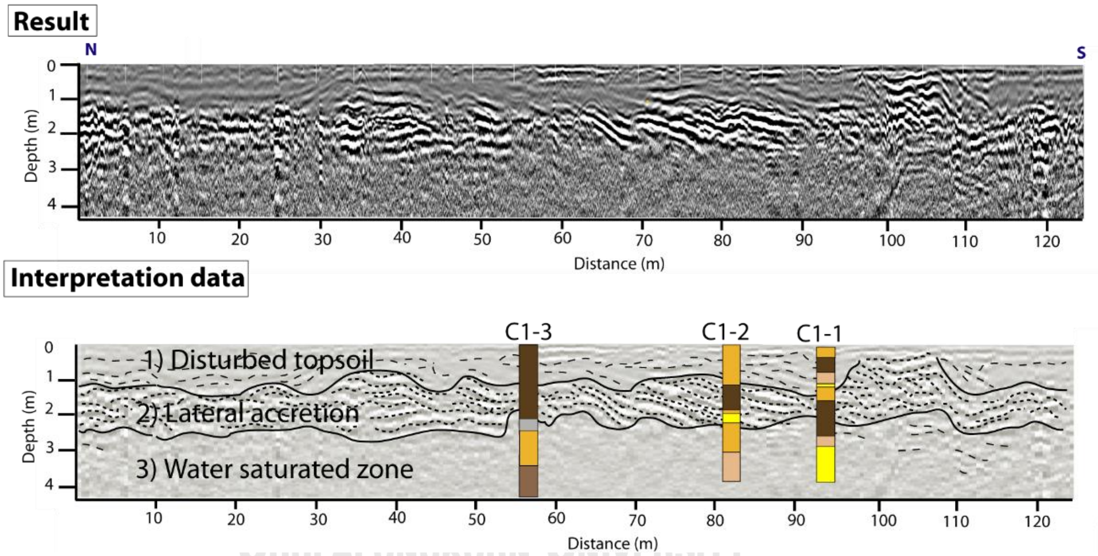


Figure 48 GPR result from location 1 surveyed on the dried channel and point bar almost NS direction120 m

2) Location 3: Ban Nong Sue Bong

This GPR profile was gathered on paleo-channel in the NW/SE direction (15 m long). Figure 49 displays parallel and unclear reflections in the upper zone. Sediments were classified as loam layer. The middle zone from 2 to 3 m was illustrated as thick black and white quite parallel orientation and, in some part, and it shows slightly wavy reflection corresponds to sandy clay and clayey sand from CMN4. These two layers were overlain on the poor reflection of water saturated clayey silt from 3 m depth.

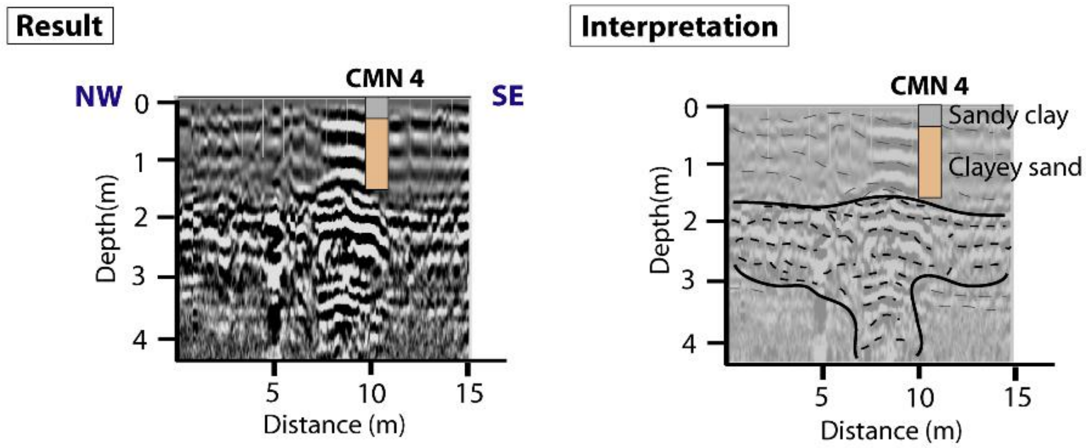


Figure 49 GPR result from location 3 surveyed on the paleo-channel almost NW/SE direction 15 m.

4.5.2 Electrical Resistivity Tomography

ERT profiles were survey from six locations (Figure 47). The target landforms are paleo-channel and floodplain. The sediment properties (sediment grain size) from borehole were compared with electrical resistivity values. The color scheme in the interpreted profile represents lithological data of ERT inversion models gathering from boreholes. Detail geophysics description from three ERT profiles is explained as follows.

1) Location 1: Near the Mun Bon Dam

Profile Line -94 m surveys across the dried channel and point bar in almost NS direction (see Figure 46 for field area and Figure 47 for location). Result of resistivity was separated into three zones as top, middle and bottom (Figure 50). Based on the lithological cross section of location 1, the top layer from 3 to -3 m presents moderate to high resistivity about 100-1200 Ω.m (in central to western sides). This zone relates to sedimentary record from C1-2 and C1-3. It is mainly composed of loam and silty sand. The resistivity value shows low resistivity (0-26 Ω.m) in the eastern side and it relates to silty clay from the borehole CMN1. The middle to bottom of ERT profile presenting moderate to low resistivity (0-93 Ω.m) from -3m to -15 m, and borehole C1-2 and C1-3 is associated with clayey silt, clayey sand and silty sand. Based on resistivity value, the bottom (left and right) of profile shows high resistivity approximately 120-1200 Ω.m.

2) Location 2: Ban Nong Sano

Three ERT survey lines at Ban Nong Sano were conducted on recent outer bank of the Mun River (line 2-1), floodplain near irrigation canal (line 2.2) and paleo-channel (line 2.3). The field location and result show as pictures and resistivity profiles in Figure 47. These locations were interpreted based on the ERT lithological classes without the sedimentary data from borehole. The result of line 2-1 (Figure 51), the upper most part from surface to 2 m-deep shows varies of resistivity value from low to moderate (0-80 Ω.m) of clayey sand and sandy silt. At for the bottom part (left side) is mainly appear low resistivity value (blue color; 0-40 Ω.m), and it is associated with clayey silt and silty clay. In the bottom-right side show moderate to high resistivity (Silty sand deposit) at 8 to 16 m deep, and it's indicated as inferred paleo-channel.

The resistivity line 2.2 gathered on the floodplain and the result of survey profile from surface to two-meter-deep show low to moderate of recent floodplain sediment (Figure 52). The zone of moderate resistivity may relate to paleo-channel location at 5 to 15 m depth which is inferred with silty sand deposit. The location near the bridge display moderate and high resistivity (red color) of concrete.

Line 2.3 of resistivity survey conducted on wide paleo-channel which can be clearly observed from 1974-aerial photographs. The result displays in Figure 53. The uppermost and the most average layer shows low apparent resistivity value about 0-3 Ω.m which is interpret as floodplain deposit (silty clay and clayey silt). This location is the rice field, and the sediment may consists of silt and clay. As for the tentative paleo-channel boundary is located at distance of survey line between 90 to 150 m and from 5 to 20 m deep. In the paleo-channel region displays the resistivity value between 50 to 70 Ω,m. As for the right side of line survey shows slightly higher resistivity value if compared with the left side because this is inner bend of paleo-channel. It may consist of coarser sediment as clayey to silty sand.

3) Location 3: Ban Nong Sue Bong

This survey line runs in nearly northwest - southeast direction across paleo-channel. ERT profile at Ban Nong Sue Bong is 94 m in length. Medium to high resistivity zone (50-180 Ω.m) was drilled within clayey sand and iron concretion bearing loam layers from boreholes C4-1 and C4-2 near GPR and ERT line survey. ERT inversion model and its interpretation as cross section are displayed in (Figure 54).

Width and depth of high resistivity zone are approximately 30 m long and the depth ranges between 10-15 m. This zone was surrounded by lower resistivity zone which is dominated by the value of resistivity less than 36 Ω.m. It is inferred as silty clay and clayey silt from the borehole CMN4. The bottom left and right of ERT profile show high resistivity value (>120 Ω.m) occurring at 10-20 m from a surface.

4) Location 4: Bank Muang Tako

This area can distinguish the geomorphological unit as medium paleo-channel (meander scar) and floodplain. The result (Figure 55) was surveyed on the road along irrigation canal at Ban Muang Tako. The lithological types of interpretation profile are based on the ERT lithological classes. The road surface consists of many kinds of material and mainly of laterite. The resistivity result shows varied of apparent resistivity value near the surface from 0 to 5 m and, the resistivity shows medium to high from 60 to 120 Ω.m. As for the depth lower than 5 m, it is the real surface as rice field and, it shows the low resistivity value (10 to 50 Ω.m). This zone may associate with silty clay and clayey silt. At the bottom of resistivity profile display moderate to slightly high from 50 to 110 Ω.m at 20 to 30 m deep which related with clayey to silty sand. It may be tentative boundary of paleo-channel.

5) Location 5: Ban Mai Don Ket

From the result of aerial photo interpretation, this area found a lot of trace of river as meander scars. The survey line 5 was gathered along the road near irrigation canal pass the two meander scars and there point bar at Ban Mai Don Ket (Figure 56). The outcome of resistivity survey exhibit resistivity value between 40 and 130 Ω.m at the location of meander scar and point bar, and the ERT lithological classes suggested that clayey to silty sand deposit. These results conform to the location and result from geomorphological map. The depth of meander scar is about 10 m deep from the surface and the channel width is about 30 m-wide (from 120 to 160 m from the survey line), and it was interpreted as sand deposit. Moreover, another meander scar found at more shallow part at 190 to 230 meter of line survey. The depth of meander scar is from the surface to 3 m deep. Underneath the result of resistivity shows low resistivity (20-30 Ω.m) which is composed of silty clay and clayey silt.

6) Location 6: Ban Wang Tabaek

ERT line runs 235m along floodplain. Survey line was made in longitudinal profile of paleo-channel in the north-south direction. Result of ERT profile (Figure 57) shows high resistivity value from 100-160 Ω.m and associated with loam and clayey to silty sand layers. The lower resistivity value from 30-50 Ω.m presents finer grain involved in clayey to silty sand from C5-2. Approximate depth of channel appears from 5 to 10 m. Moreover, the deeper channels were found at 20 to 25 m from the surface. On the other hand, high to medium resistivity value is enclosed with low resistivity value (0-20 Ω.m) probably comprises of fined grain sediments such as silty clay, sandy clay and clayey silt from C5-1.

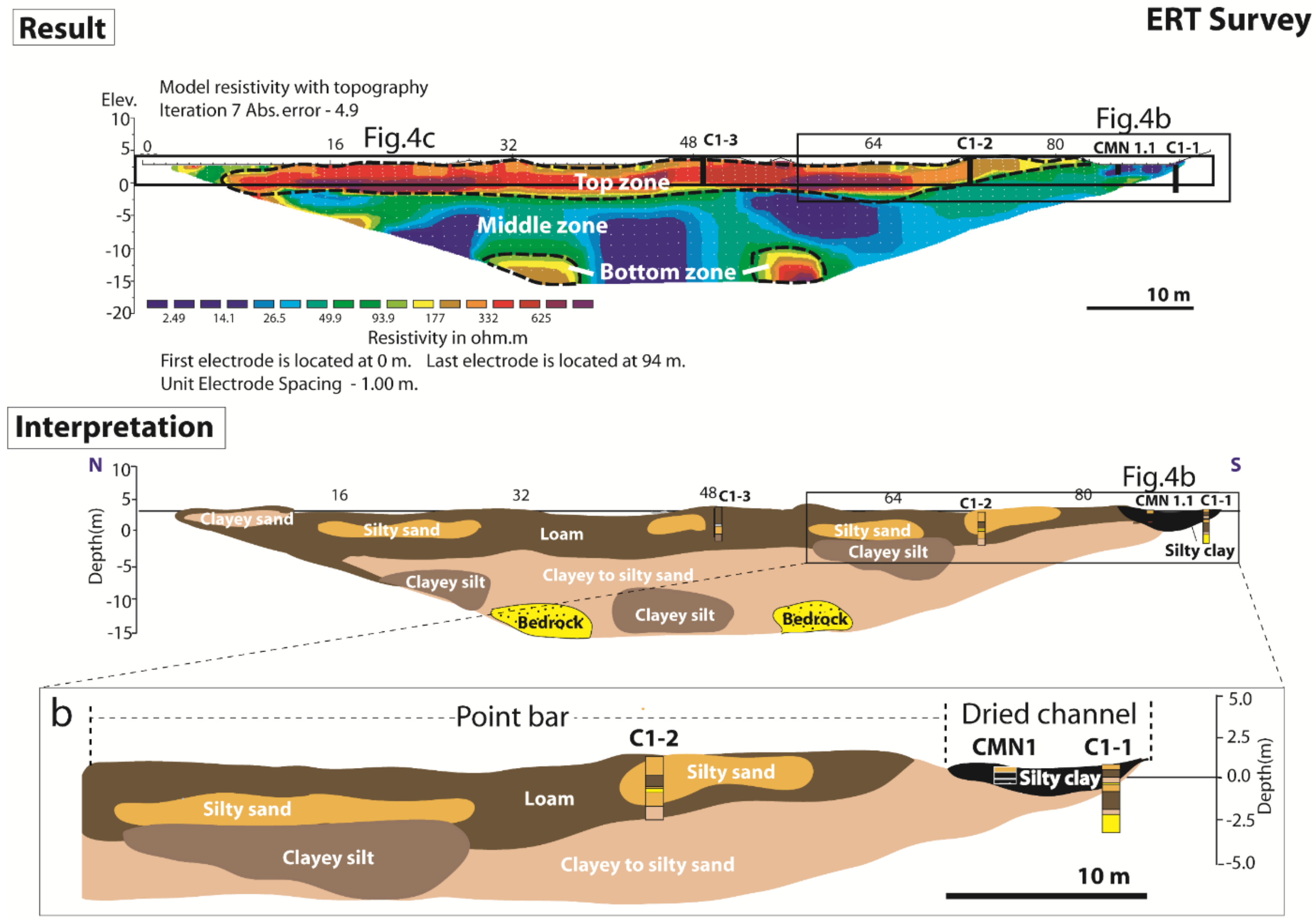


Figure ERT profiles and their interpreted cross-section profiles from the dried channel and point bar at location1 (near the Mun Bon Dam) using the ERT shows in 4a and 4b (close up from eastern side of 4a).

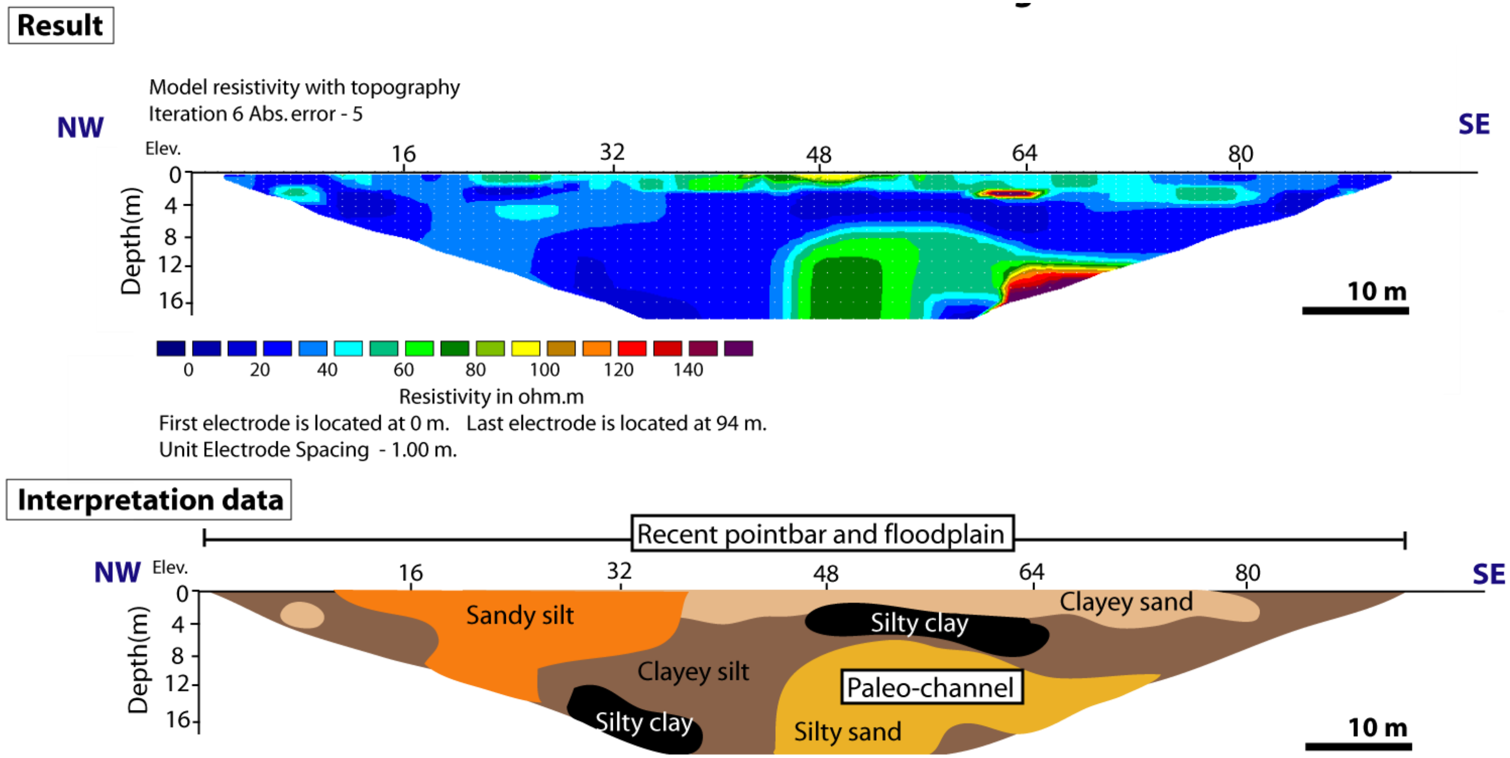


Figure 51 ERT-94 m profiles and their interpreted cross-section profiles from the point bar and floodplain of near the concave bank of the recent Mun River at location 2-1 (Ban Nong Sano) using the ERT shows moderate resistivity of recent point bar deposit. At the depth 8 to 16 found paleo-channel.

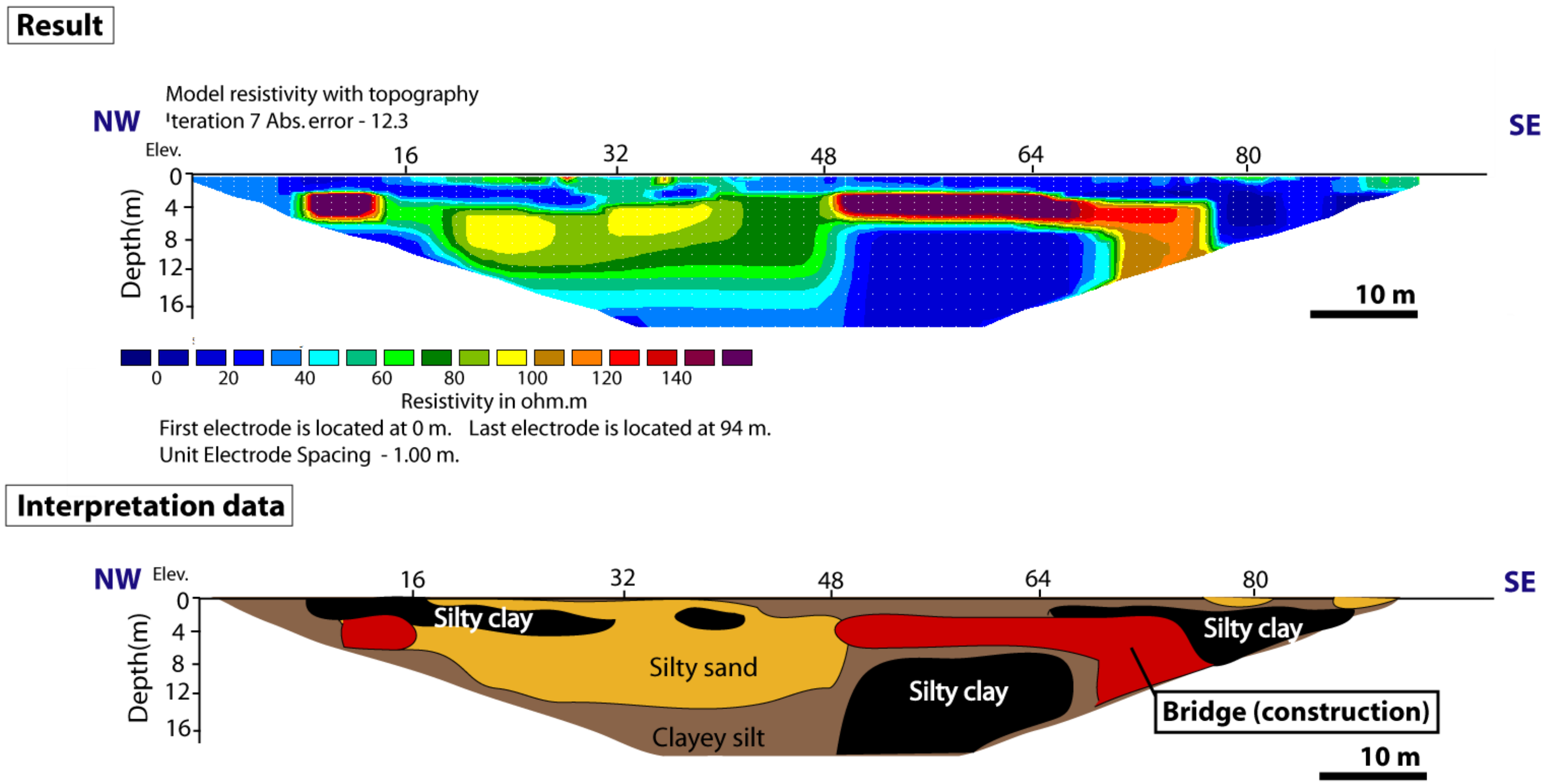


Figure 52 ERT-94 m profiles and their interpreted cross-section the Mun River floodplain at location 2-2 (Ban Nong Sano) using the ERT shows moderate resistivity of inferred paleo-channel deposit. Zone of high resistivity is associated with the bridge construction location

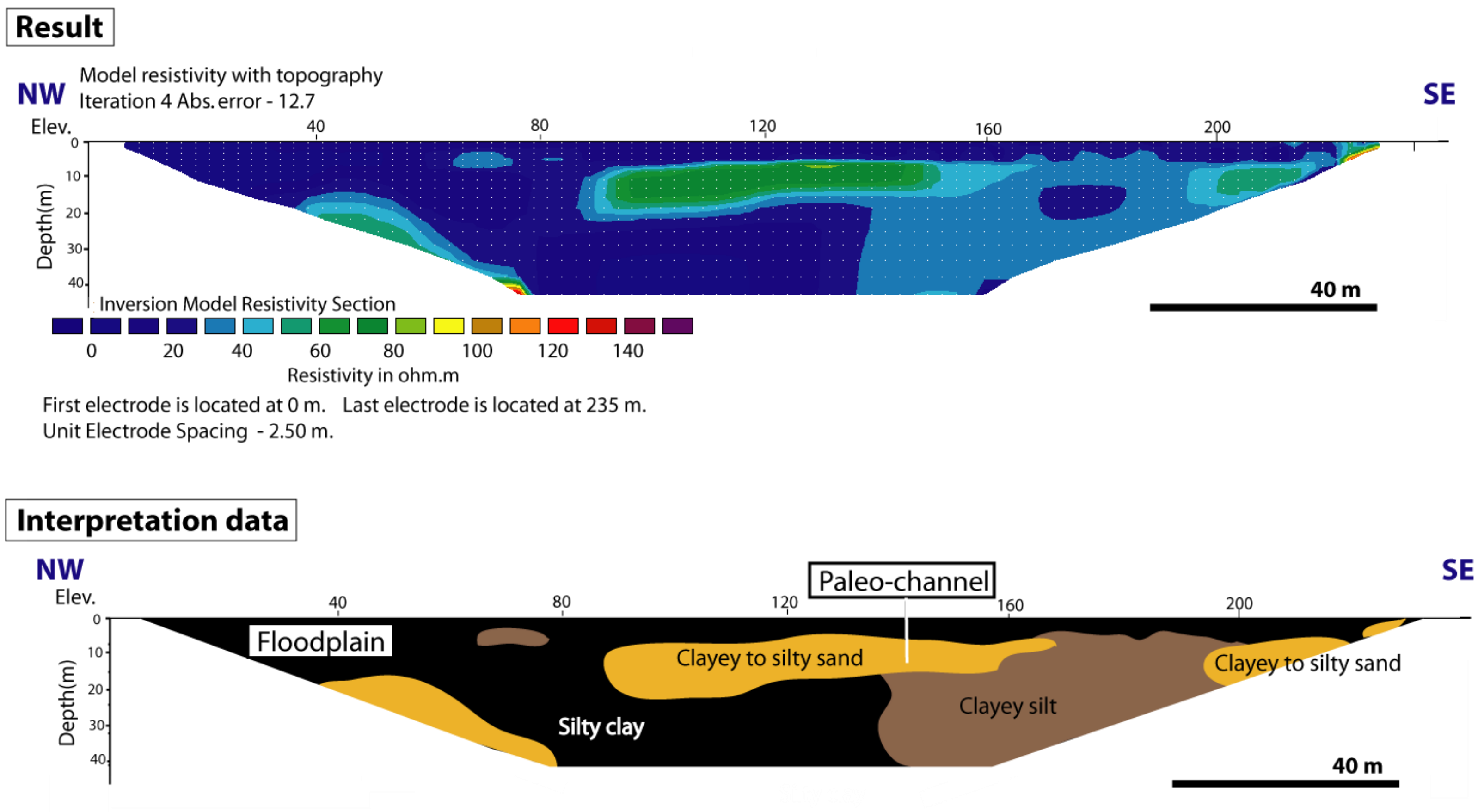


Figure 53 ERT-235 m profiles and their interpreted cross-section the paleo-channel and floodplain at location 2-3 (Ban Nong Sano) using the ERT shows moderate resistivity of inferred paleo-channel deposit.

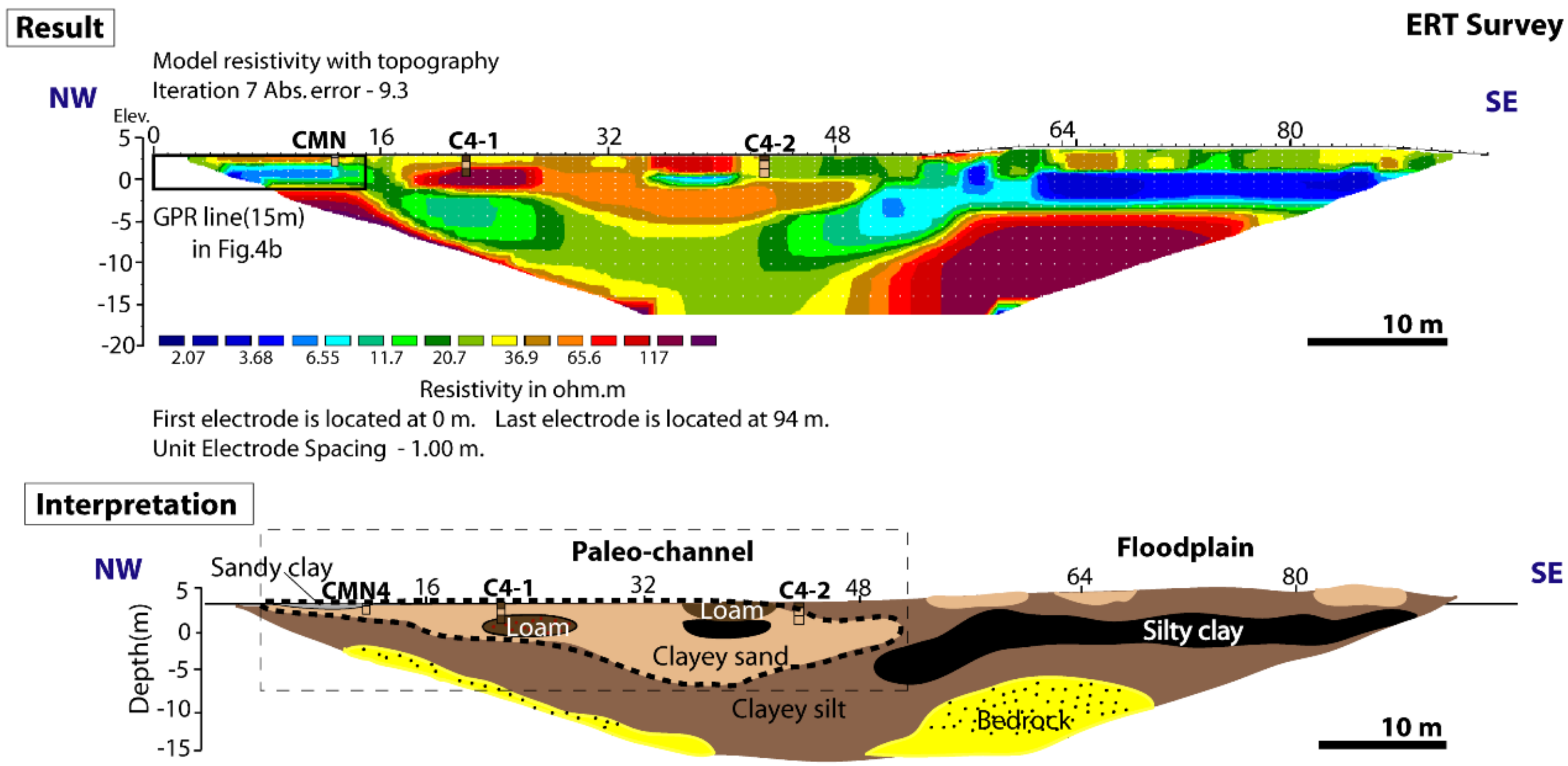


Figure 54 The inversion model of the ERT line - 94 m and its interpretation based on resistivity and boreholes data. It was collected from paleo-channel at location 3 (Ban Nong Sue Bong).

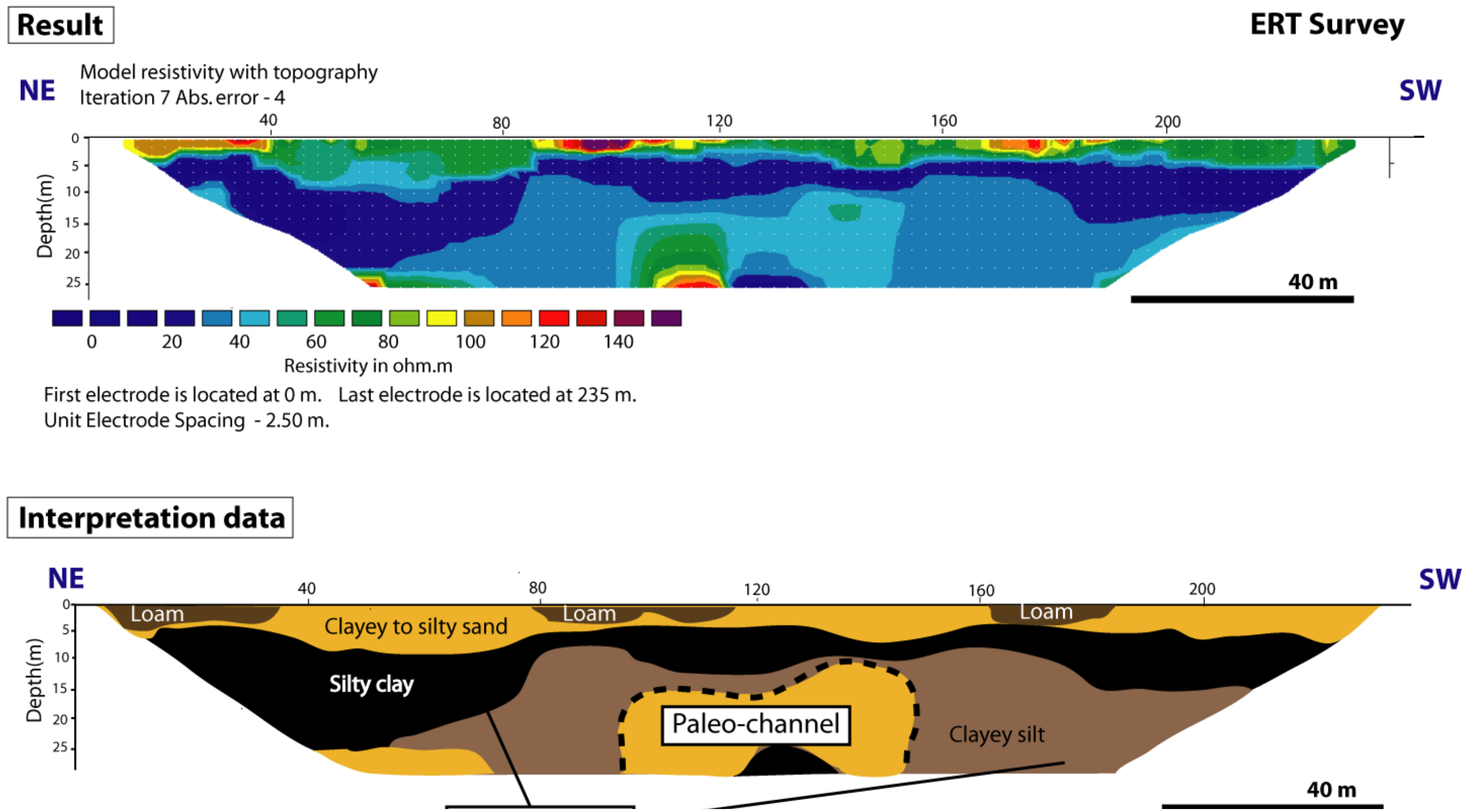


Figure 55 ERT-235 m profiles and their interpreted cross-section the paleo-channel at location 4 (Ban Muang Tako) using the ERT shows moderate resistivity of inferred paleo-channel deposit at the center of profiles at 10 to 25 m depth. The uppermost layer (0 to 7 m) found high to moderate resistivity of road construction material on the road along irrigation channel.

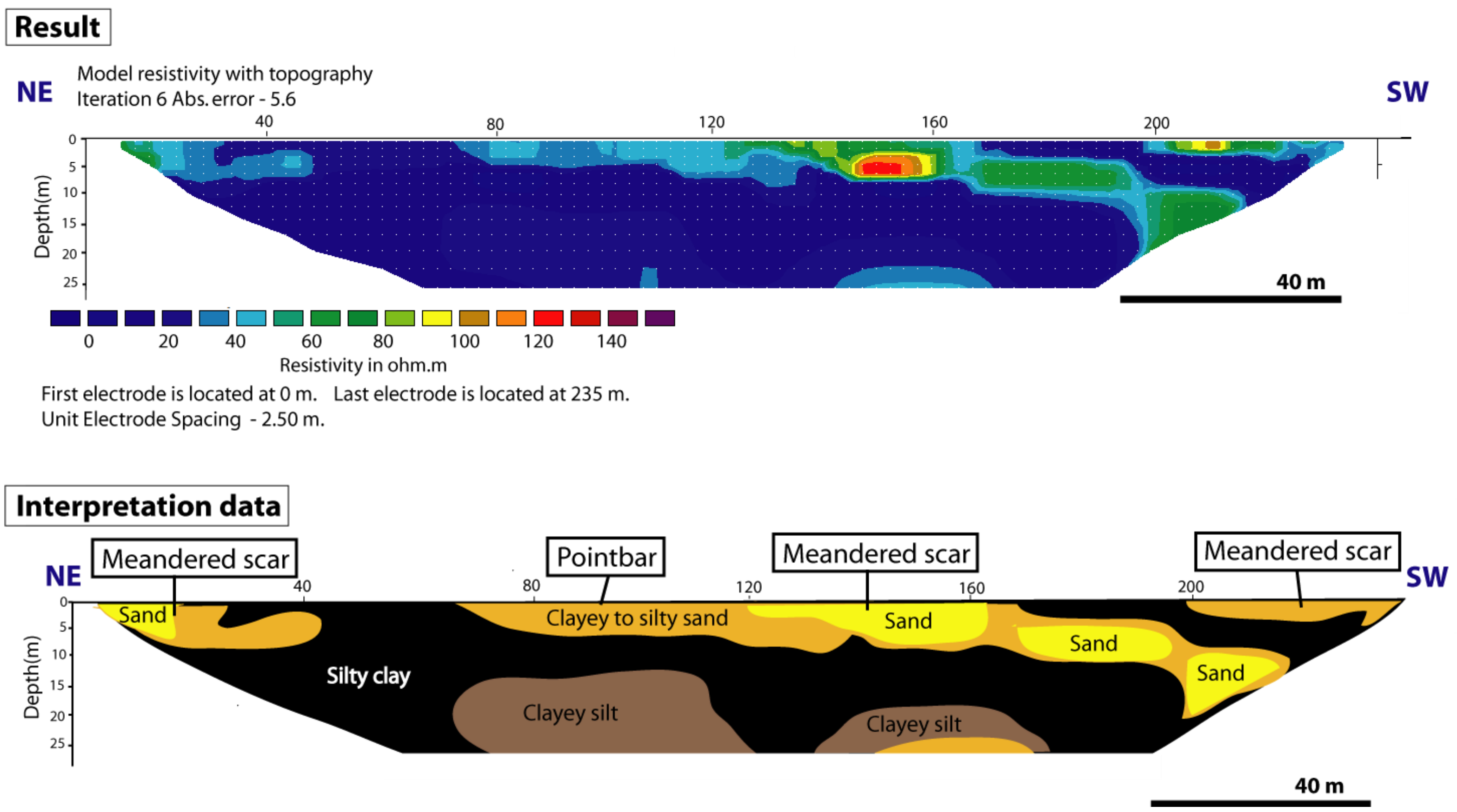


Figure 56 ERT geophysical profile surveyed over paleo-channels (longtitudinal profile). Profile shows inversion model of ERT profile line-235 m and its interpretation based on resistivity value and borehore data at location 6 (Ban Mai Don Ket).

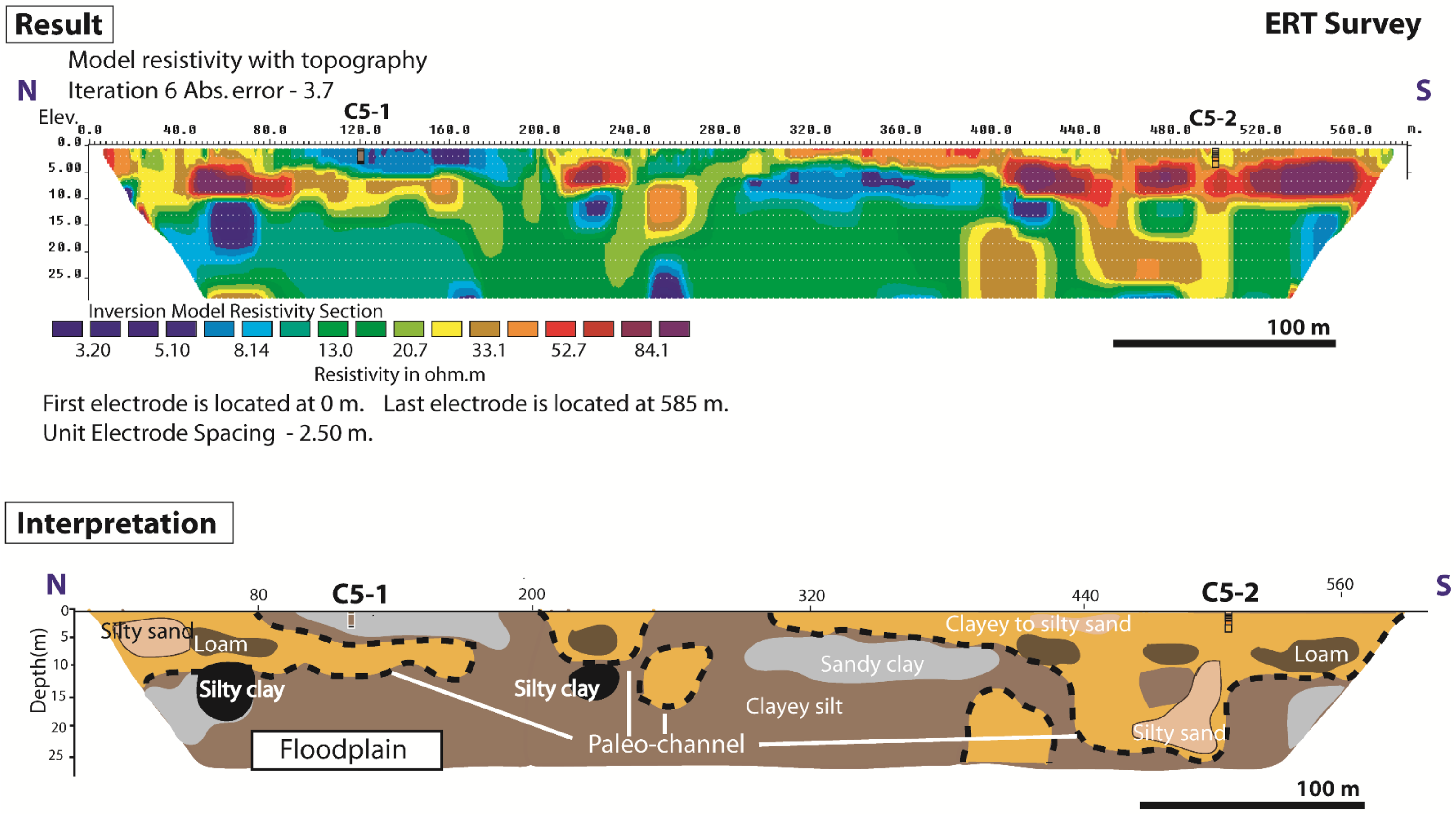


Figure 57 ERT geophysical profile surveyed over floodplain and paleo-channel (longtitudinal profile). Profile shows inversion model of ERT profile line -585 m and its interpretation based on resistivity value and borehore data at location 6 (Ban Wang Tabeak).

CHAPTER V
Discussions

5.1 Evidence of paleo-channels

The deposition on point bar and erosion at the outside bend is the main process of the meandering river system. This causes the river migrate toward the side and downstream, so the closer river bend get cut off during flood event and forms oxbow lake (Reynolds et al., 2012). Therefore, many landforms in this study area including meandered scars and oxbow lakes are present on floodplain (e.g.,(Kondolf et al., 2005). Paleo-channels can be observed clearly from aerial photos taken in 1974 more than the other periods because of the extensive human activity such as the agriculture, housing area, domestic animals and increasing the number of factory nearby the river (Gosa, 2012). Moreover, the increasing in land surface elevation by aggradations during flooding may be another factor, so the meandered scars can't clearly observe in the recent SPOT image.

5.2 The characteristic of paleo-channel and the recent Mun River (width and SI)

Paleo-channels recognized from this area having their variety of channel sizes existing on the same geological terrain. Two different sets of paleo-channel were categorized as medium and small-sized paleo-channel groups. The recent Mun River is narrowest compared with the paleo channels. The width of medium-sized channel is 20-200 m wide, whereas the small-sized paleo-channel, and the recent Mun River were classified as small-sized channel (< 20 m wide) (David, 2003). The width of small-sized paleo-channels shows slightly change about 0-6 m and similar to the recent Mun River. Moreover, the locations of small-sized channels were found near the recent river, and it may relate to the Mun River cut off process. Increasing in width of medium-sized paleo-channel may result in increasing of sediment supply and decreasing in channel stability in the past (Miall, 2013),so it may occur in the different condition of fluvial process. Water velocity, discharge and sediment load in the past are among physical factors that clearly different from the present. Water naturally drains from big drainage basin from highland area of the Sankamphaeng Mountain Range to downstream. The higher amount of water volume and the more velocity of river flow compared with the present form lead the river to flow easier and faster throughout the channel. The more stream power in higher discharge and velocity can carry the large amount of sediments. Then, both of the lateral and vertical erosion made channel wider and meander can free-swing in the past more than the present. The width of paleo-channels that is wider than present indicates that the existence of these paleo-channels in place far from headwater (at the middle river reach) and developed on small channel gradient (Li et al., 2012). In conclusion, the comparison of SI of medium-sized paleo-channel, small-sized paleo-channel and the Mun River revealed that most of them were categorized as “meandering river” (Hooke, 2007, Masalimova et al., 2015) which usually develops on low gradient floodplain and includes of sand and silt deposit (Hogan and Luzi, 2010). Channel width was slightly increased from dam site to downstream area of the recent Mun River (Reach 4 to 8 in Figure 37c bottom). Channel width in the downstream of the study area was possibly affected by check dam, digging out of Mun River. Moreover, land use change from factory and agriculture has an effect on the river channel (Gosa, 2012).

5.3 Geomorphic parameters before and after the Mun Bon dam construction

The temporary base levels of the Mun River are probably modified after the Mun River was dammed by the Mun Bon Dam. Dams are often regarded as the most dominant form of human impact on fluvial systems (Ronald et al., 2013). Changing of fluvial process and landform in the natural condition, many parameters may control the Mun River behavior such as source and supply of sediments, slope of the alluvial plain

Two primary drivers of change to fluvial system in respond to dam change include flow regime and changes in sediment regime. Flow and sediment regime modifications occur over short period, however, geomorphic impacts that extend over tens to hundreds of years (Marren et al., 2014). The discharge data from water station no. M.49 (see the location in appendix) in the study area shows the difference in water level before and after dam construction from 1966 to 2016 (Figure 58). Water level in the Mun River is higher than the period after the Mun Bon Dam construction about 1 to 3 m. On the other hand, the lowest water level increased from 1 to 2 m after dam construction (Royal Irrigation Department (Thailand, 2013). In case of sediment regime when the river reduces flow discharge, the river continues meandering and becomes high sinuosity (Li et al. 2012), however in the study area, the relationship between Rc and bend migration per year shows low erosion rate from 2004 to 2015 (Figure 39d). Channel width and meander migration rate from locations 6 to 10 also decreased (Figure 39b and c) because the topographic elevations from the locations 6 to 10 are lower than those recognized from the Mun Bon Dam area.

The apparent change of channel width and migration rate after dam construction is from the evidence of fluvial geomorphologic change in this area. The comparison of channel width before and after the Mun Bon Dam construction notably shows expansion of channel width in locations 1, 2, 3, 9 and 10 (Figure 39b). On the other hand, channel width decreased in locations 4 to 8. River channel shows the increasing in lateral migration rate in locations 3, 4, 5 and 10, but the rate reduces in locations 2, 6, 7, 8 and 9 (Figure 39c). The different migration rate occurs in individual bend because the lateral accretion is not continuous process or it occurs episodically (Melville and Coleman, 2000). Additional reason is made by the effect on river channel (channel width) rectification that riparian on the side of floodplain was found.

5.3.1 River Bank Erosion

In this study, the degree of tightness of meander bends is also represented by Rc. The wide bend shows low Rc value while high Rc value implies tight river bend (Figure 39a). Rc trend from 1974, 1986, 2004 to 2015 shows slightly change with similar trend in the same location. The lowest and highest Rc values were shown in locations 4 and 9. Relationship between meander migration rate and bend curvature suggested that the Mun River in Khon Buri and Chok Chai areas possess low erosion rate since 1974 to the present (Figure 39d). Migration rate versus bend curvature (Rc/W) is less than 5 that coincides as stable river bank.

The Mun River bank in this area is mainly composed of silt and clay layer in the upper part (1 to 2 m from the surface). On the other hand, the lower part (2 to 4 m) is associated with compacted clay layer with iron concretion and weathered red siltstone and sandstone bedrock which are resistant to lateral erosion. Moreover, the very low water level and the low flow velocity may inhibit the river bank erosion. In such a case, aerial photographs were once again used for measuring lateral migration rates of river bend. Meander migration rate versus bend curvature (Rc/W) of the Mun River was plotted and shown in Figure 39d. The value of Rc/W ranges from 1 to 2, this means chute or neck cut offs can be formed (dark grey color). Bank erosion exists in zone of Rc/W from 2.5 to 4 (red color) (Figure 39d). Low erosion rate occurs in zone of Rc/W more than 5 (Nanson and Hickin 1983). Flow direction of Mun River (in 1974, 1986 and 2011) on reach no. 5 follows the same channel as previous direction with slightly meander migration to the left side. Migration rate per year (locations 1 to 5) also increased from 2004 to 2015 (after the Mun Bon Dam construction) (see location 4 in Figure 39c).

5.3.2 Effect of geomorphic parameters to floodplain after dam

In this study, we found that geomorphic parameters have an effect on floodplain topography. Slightly higher floodplain topography of the area between locations 3 and 5 could lead to natural obstacle (Figure 39). Due to decreasing in velocity of river flow, sediments were carried by slow water flow regime. Then, they were settled and deposited. This process results in the increasing of later migration rate (Figure 39 c). Rc of location 10 is also highest value because the curvature of river became closer. The other possible factor is from the construction of many check dams. Check dams are used for irrigation purposes and measuring the water level (see the location (star symbols) in Figure 39). The hydrological balance possibly changes sediment budget and water volume in a downstream area because of the effect of water drainage (Marren et al., 2014). Flow regulation causes reversing natural flow seasonality.

Water recharge and discharge from the Mun Bon Dam from 2005, 2010 and 2015 shows different water level. Recharge represents natural situation when river flows to the dam. According to Figure 58b, the highest peak of recharge is about September to October, but the highest peak of discharge is around March (2005 and 2010) and October (2015). These peaks confirmed the seasonal variation of water discharge in the Mun River after the Mun Bon Dam construction (Royal Irrigation Department Thailand 2016).

Likewise, the Mun Bon Dam is also used for irrigation purpose. Broadly thought, dam is likely to be reduced the magnitude and frequency of medium to high flow and the variability of low flows is likely to be raised where water is released for irrigation purpose (Marren et al. 2014). Therefore, water level in summer period decreases, but the winter period increased in discharge volume more than naturally condition. Consequently, the Mun River channel may change from this factor depend on the degree of river erosion. However, due to the nature meander process in this area show the different migration rate in individual bend and bank composition varies from area t area, so the river width is wider from some locations (see locations 1, 2, 3, 9 and 10 in Figure 39b). Dam is highly effective to sediment traps and the channel migration is a discontinuous process. Several studies of dam impact have reported a reduction in meander migration rates (Marren et al., 2014, Richard et al., 2005). In the context of floodplain impact, the reduction of sediment load may enhance rate of bank erosion and lateral migration. Composition of bank profile and slow and low flow velocity in the study area are the importance factors for limit the bank erosion. Sediment supply and bank erosion is reduced; therefore, lateral migration rate tends to decline. Decrease of lateral migration rate can be seen in locations 6 to 9.

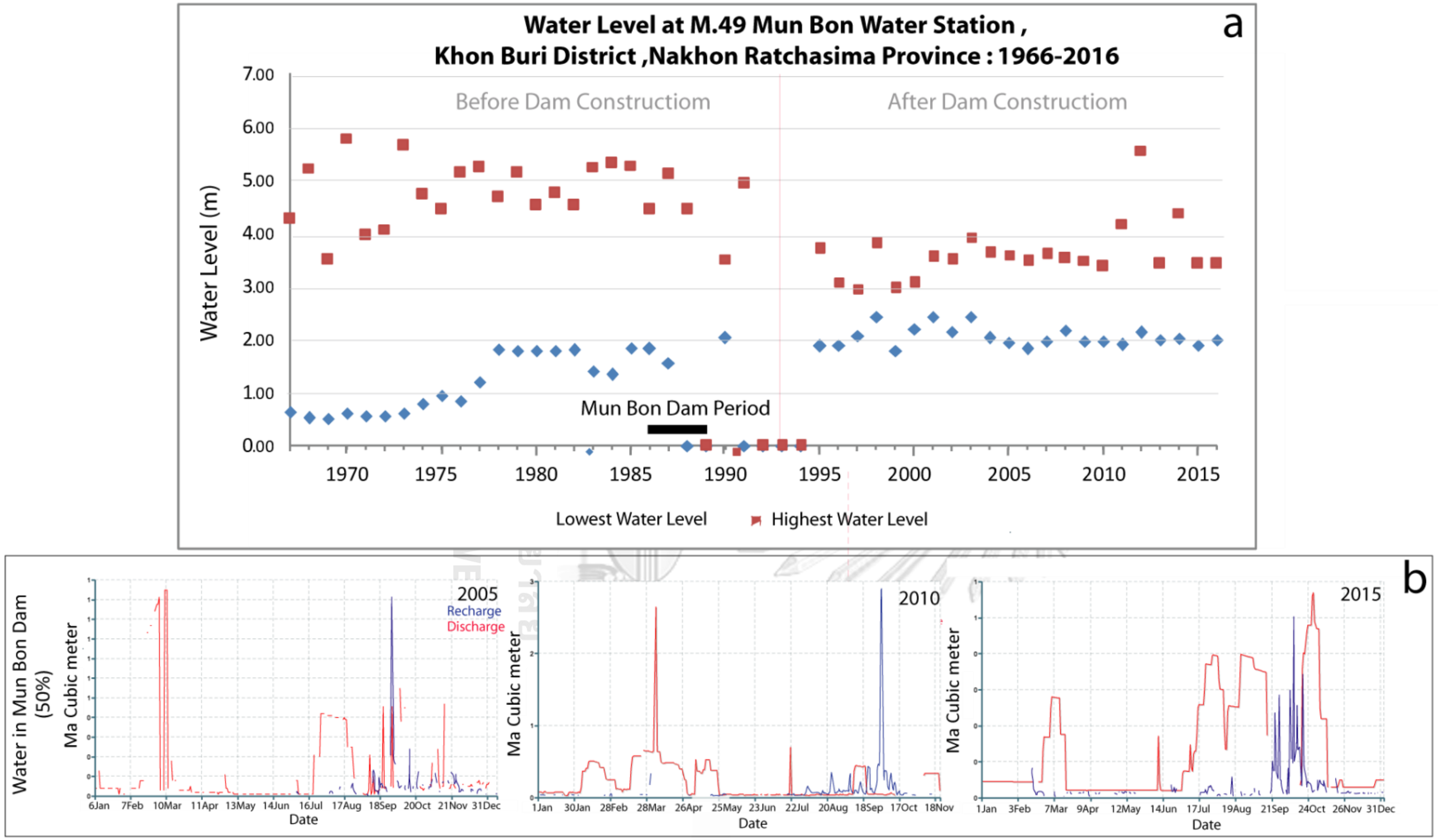


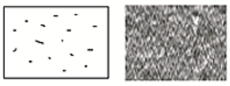
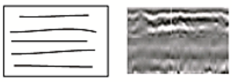
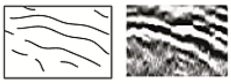
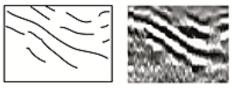
Figure 58 Water level at station no. M49 (Khon Buri District, Changwat Nakhon Ratchasima) shows the lowest and highest water levels in 1966 to 2016 (a). Water recharge and discharge to the Mun Bon Dam in 2005, 2010 and 2015 (b) (Nimnate et al., 2017).

5.4 GPR radar facies of fluvial deposit

Based on radar reflection patterns in the study area, radar facies were mainly interpreted from location 1. Radar facies from fluvial deposit can be divided into three groups (reflection free, layer reflection and discontinuous) (Table 5). Firstly, reflection free (Facies 1) represents the zone of attenuated energy from sediments contain high clay content or highly conductive dissolve mineral in groundwater (water saturated zone). Secondly, clinoform can be separated into two facies (shingled and incline reflections) which depends on dip angle of sediment layer. Shingled reflection (Facies 2) displays the inclination angle approximately 5-20°. Incline reflection (Facies 3) exhibits sigmoidal oblique or parallel layer with dipping angle approximately 15-45°. These two clinoform reflections were interpreted as well to moderate stratified dipping bed which is formed by lateral migration process on point bars. Finally, hummocky reflection (Facies 4) of discontinuous group shows discontinuous or disrupted reflections. This radar facie was interpreted as crudely stratified sand or gravel bed deposit with obscured by diffraction. GPR reflection patterns on the radar record of point bar deposit (Table 5).

The apparent attenuation of the radar signal increased as the content of clay-size particles in the subsurface increased (Beres and Haeni, 1991). This is explained by the organic and clay deposits, ground water level, roughly land surface and dense vegetation may attenuate a GPR signal concluded that fine-coarse interfaces cannot be detected using GPR method (Słowik, 2011).

Table 5 Three groups of radar facies and their interpretation display GPR reflection patterns from point bar deposit in the study area. Radar facies is classified based on Milan Beres and Heani (1991) and Hickin et al (2009).

GROUP	SCHEMATIC EXAMPLE	GPR FACIES	DESCRIPTION	INTERPRETATION (Milan Beres and Heani, 1991; Hickin et al., 2009)
Reflection free		Facies 1 Reflection free	High conductive loses, Poorly defined reflection pattern and lack of pen-etration profile	1. Attenuated energy 2. Massive homogeneous lithological unit 3. High clay content
Layer reflection Continuous to subhorizontal		Facies 2 Parallel reflection	Lateral continuous (10-30m), Parallel uniform horizontal to subhorizon-tal	- Well stratified horizontal bedding, vertical accretion - Silt laminated to thin bed - Sand laminated to thick bed
Clinoform		Facies 3 Shingled reflection	Short (5-10m) incline (5-20 degree) shingled reflections	- Well to moderate stratified stratified dipping bedding, lateral accretion, slipface of migration bedform
		Facies 4 Incline reflection	Short (<10m) sigmoid oblique, tangential or parallel, incline (15-45 degree) reflections	- Well to moderate stratified dipping, lateral accretion slipface of migration -Migration of channel bar, modern floodplain
Discontinuous		Facies 5 Hummocky reflection	Discontinuous (5-20 m), hummocky or disrupted relfections	- Sand bed or gravel bed - Crudely stratified to massive deposit obscured by diffractions

5.5 Relationship between fluvial sediment and ERT lithological classes

The sediment properties of subsurface fluvial sediment from on-site boreholes and results of apparent resistivity from ERT surveys are shown in Table 6. From this relationship, the lithological classes can be classified from all the results. The thickness of fluvial deposit from 5 to 30 m depth is clearly revealed both of vertical and horizontal changes.

Based on resistivity profile results from location 1, the upper most part, the cultivated soil with low moisture contents depicts high resistivity value (orange to purple color). This zone was interpreted as point bar deposit and it is concordant with GPR and sedimentological data from boreholes. Point bar sediments consist mainly of sand (clayey to silty sand) and loam in C1-2 and C1-3. The middle zone of ERT profile in location 1 displays low resistivity because the pores between sediment grains are saturated with groundwater, therefore, the higher resistivity shows in this zone Composition of sediments is associated with higher clay content such as clayey silt and clayey to silty sand than the upper part. High resistivity value (orange to purple color) from the bottom part of profile was related to bedrock which is mainly composed of sandstone, siltstone and conglomeritic sandstone of Phu Phan formation (Meesook and Saengsrichan, 2011).

Based on ERT surveyed across paleo-channel at location 2 (Ban Nong Sue Bong), the outcome displays medium to high resistivity value body. It shows channel-liked shape of buried paleo-channel from the surface to 10 m depth in yellow to dark red color. Sediment mainly consists of clayey sand and loam layers deposited in channel (C4-1 and C4-2). This paleo-channel was enclosed with low resistivity value displays in green to blue color. Finer grain sediment as clayey silt and silty clay can be carried during flood and suspended in the moving water which rises above the channel and being to spread out. Finally, this fine grain sediments deposit along the parallel channel and form floodplain (Reynolds et al., 2012). The bottom part of profile also displays high resistivity of pebbly sandstone bedrock consisting of siltstone and sandstone (Meesook and Saengsrichan, 2011).

The longitudinal ERT profile of location 3 was carried out in floodplain of the recent Mun River at Ban Wang Tabaek. High to moderate resistivity value was interpreted as in-channel sediment deposition which is composed of loam and clayey to silty sand. On the contrary, low resistivity value is associated with fine grain deposit such as clayey silt and silty clay. Floodplain sediment is associated with loam, clayey silt and silty clay deposited on both sides of floodplain. On the other hand, paleo-channels deposit comprises coarser sediments such as loam, sand (clayey to silty sand) and silt (clayey to sandy silt).

The integration of stratigraphy and sediment properties defined from boreholes, and three resistivity profiles of ERT survey allow us to distinguish ERT lithological classes of subsurface sediments in the study area. Resistivity values for the lithological types are defined in Table 6 Five lithological classes were deduced from the relationship between sediment grain size and their electrical resistivity properties. Clay, silt, sand, loam and bedrock demonstrated the results of resistivity ranges were demonstrated as 0-11 Ω.m, 11-33 Ω.m, 20-120 Ω.m, 62-160 Ω.m, and 120-160 Ω.m, respectively, and this relationship of physical properties and apparent resistivity can apply for the ERT survey in adjacent area or other river on the rim of the Khorat Plateau which resembles in geological setting. After ERT survey, the data can be compared and classified the sediment properties follow this table.

Table 6 ERT lithology classes and GPR radar facies were identified in the study area. Locations of water station M 49 (Mun River Watershed)

Resistivity (Ωm)	ETR lithological classes
0-11	Clay (Silty to Sandy clay)
11-33	Silt (Clayey silt to Sandy silt)
20-120	Sand (Clayey sand, Silty sand and Sand)
62-160	Loam
120-160	Bedrock

CHAPTER VI
Conclusions

6.1 Aerial photograph interpretation

The fluvial geomorphology of the study area in 1974, 1986 and 2011 was compared. Based on the result of the aerial photograph interpretation in 1974, the numerous of meandered scars were found on the both side of the Mun River floodplain, and there show various size and continuity to each other (look like a river). In terms of river classification by Brice (Hooke, 2007), the Mun River in 1974 was classified as G1type (two phases, bimodal bankfull, sinuosity, equip width) and B2 type (single, wider at bend, no bars). The aerial interpretation in 1986 shows some meandered scars with the discontinuous if compared with the aerial photo in 1974. The river type is B2 type based on Brice River Classification. The fluvial geomorphology from satellite image (2011) displays the oxbow lakes at the Chok Chai area. The meandered scars are rarely, and the river type is categorized as B2 type.

On the other hand, the study area was divided into five reaches (1-5 from the Mun Bon Dam to the downstream area). Reach 1 shows dried channel which is the effect from dam construction, and the sinuosity index is decreased from 1974 to 2011. Cutoff process and abundant of meandered scars especially on the left side of floodplain were dominated in Reach 2 and 3. According to the study finding on the Reach 4 and 5, the various size of meandered scars found on the right side of floodplain. The migration of the river found in some bend in Reach 4, but the river flows on the same channel in Reach 5.

6.2 Geomorphic planform analysis

6.2.1 Comparing the paleo-channel and the recent Mun River

Sinuosity index of paleo-channels and the recent Mun River indicate meandering river system. Abandoned channels were observed clearly on floodplain from aerial photographs taken in 1974 at both sides of the Mun River. Two different groups of paleo-channels have the variety of channel size(Dey, 2014). This can be explained by geomorphic planform parameters in the area. Stream power and velocity from highland of this drainage basin (the Sankamphaeng Mountain Range) are capable to carry large amount of sediment to form floodplain downstream, thus the river can be shifted laterally and naturally.

6.2.2 Comparing the geomorphic parameter before and after the Mun Bon Dam construction

Alteration in river planform parameters such as channel width and radius of curvature might be the influence of dam construction to the development of meandering river. Some meander bends decrease in channel width; in contrast, others become wider. This is because the discharge fluctuation leads to the sedimentary regime change in some locations. High topography by small hill may behave as natural obstruction leading to the reduction of the Mun River flow velocity and contribute to sediments deposition. By this reason, lateral migration rate has increased and channel has become sinuous. As a whole, radius of curvature of recent Mun River and abandoned channels in Khon Buri and Chok Chai areas indicates low erosion rate. Rc is associated with the degree of tightness of the river bend. Rc shows similar trending from 1974 to 2015.

Channel stability of the Mun River from the past to the present behaviour poses the value more than 5. Therefore, it suggested that low rate of erosion probably because of very low gradient topography northward, low water level with slow flow velocity and resistant bank composition. The construction of Mun Bon Dam has slightly affected the geomorphologic changes in the Mun River course especially river migration. The seasonal change of water discharge and recharge is also indirect factor affecting meandering process after dam construction. The peak of discharge is common in summer (March to April) but, recharge is on September. Increasing in channel migration can be seen at some location, but lateral migration rate was decreased after dam construction. In the study area, the different migration rate occurs in individual bend, thus, the lateral accretion is not continuous process.

6.3 Field investigation and grain size analysis of fluvial sediment

Each morphologic unit was examined the lithology of the sediments form boreholes, and the main target is paleo channels (meandered scars). Hand auger and percussion drilling were used to drill the subsurface sediment for verified the result from shallow geophysical survey. Sediments were gathered from borehole by hand auger and picked up from each layer. Then the sediments from each landform were classified by Sheppard's classification system. As for the bank profile, the recent Mun River sediment deposit is the main target.

According to the study finding, sedimentary data from borehole in the field and result of grain size analysis shows the type of sediment deposit from each landform as point bar, floodplain, meandered scar and river bank. Point bar sediments mainly consist of silty sand, clayey sand, sand and loam. Clayey silt and silty clay are the compositions of floodplain while the meandered scars or paleo channels mainly consist of silty sand, sandy to clayey silt and silty clay. As for the bank sediment, sediments cores were drilled on the concave bank, and the main compositions are sand, silty sand, loam and clay.

The bank profiles surveyed at Ban Nong Khla and Ban Khi Tun. Bank sediment compositions are mainly composed of clay silt and very fine sand. At Ban Nong Klha found iron concretion that is indicated high evaporation. At Ban Khi Tun the bottom part of the bank profile found the weathered maroon siltstone to sandstone bedrock.

6.4 Geophysical survey of fluvial subsurface sediment

Characteristic of subsurface sediment deposition from two sites of GPR survey and eight sites of ERT has been interpreted and combined with sedimentological data from boreholes.

Trace of paleo-channels and meandered scar can be recognized based on surface geomorphological mapping from aerial photographs. Then, the characteristic of subsurface sedimentary deposition from GPR and ERT has been carried out together with sedimentological properties analysis from boreholes. The combination of resistivity ERT and sedimentological data in this study allowed us to precisely define

ERT lithological classes and their relationship with sediment grain size and electrical resistivity values

GPR profiles in this study show sedimentological structures as radar reflection facies. Sedimentological properties of subsurface from ERT and GPR provide a broad understanding of the subsurface geology. GPR proved valuable in depicting internal structure of fluvial sediments in particular point bar deposition. GPR radar facies from point bar deposit presents the inclined layer reflection of lateral accretion.

ERT profiles of point bar and dried channel display low resistivity value associated with silty clay deposit from dried channel. Point bar deposit shows moderated to high resistivity from inversion model (100-1200 Ω.m) and it associated with loam and clayey to silty sand from location 1.

ERT profile gathered from buried paleo-channel (Ban Nong Sua Bong) shows moderate to high resistivity value. It is associated with clayey sand deposit. The channel geometry is approximately 30 m wide and 10 m depth. Floodplain deposit consists of clayey silt and silty clay, and it demonstrated by low resistivity zone (0-36 Ω.m). GPR survey on the western side of the ERT profile passes throughout clayey silt and silty clay layer of floodplain deposit, therefore, the radar signal shows parallel unclear reflection.

Longitudinal ERT profile at Ban Wang Tabaek was investigated on floodplain and paleo-channels. High resistivity value (100-160 Ω.m) was interpreted as channel sediment deposit at 5 to 10 m depth. Borehole data are involved in loam and clayey to silty sand. Silty to sandy clay and clayey silt deposition conforms to low resistivity value (0-20 Ω.m), and it is applicable for floodplain deposit.

Moreover, the ERT lithological classes from this study can be apply for the ERT survey in adjacent area where are the same lithological conditions as alluvial sediment on sandstone bedrock. This study area mainly consists of floodplain and meandered scars sediment succession, so the ERT is more effective for determined large scale subsurface fluvial landforms.

6.5 Recommendations

In this research the main purposes were proved. However in discussion and conclusion parts need more detail form further research for fulfill the knowledge.

First, lots of paleo-channels were found on the floodplain. For the size of paleo-channel from the ERT that showed the tentative boundary between channel and floodplain deposit. It isn't representative width of river channel because the migration process of channel occur. For the recommendation, the paleo-channel should be done the site excavation or trenching for observe the sedimentary structures such as channel erosional surface at the base and cross bedding of lateral accretion. Moreover, the absolute age of paleo-channel should be dated for determine the rate of river avulsion in this study area and history before dam construction.

Second, the effect of dam to the annually sediment supply should be measured for the migration rate per year, comparing sediment erosion rate during summer and cool seasons and bank erosion rate in each meander.

Moreover, the pros and cons about the dam to adjacent community should be determined about frequency and magnitude of flood.

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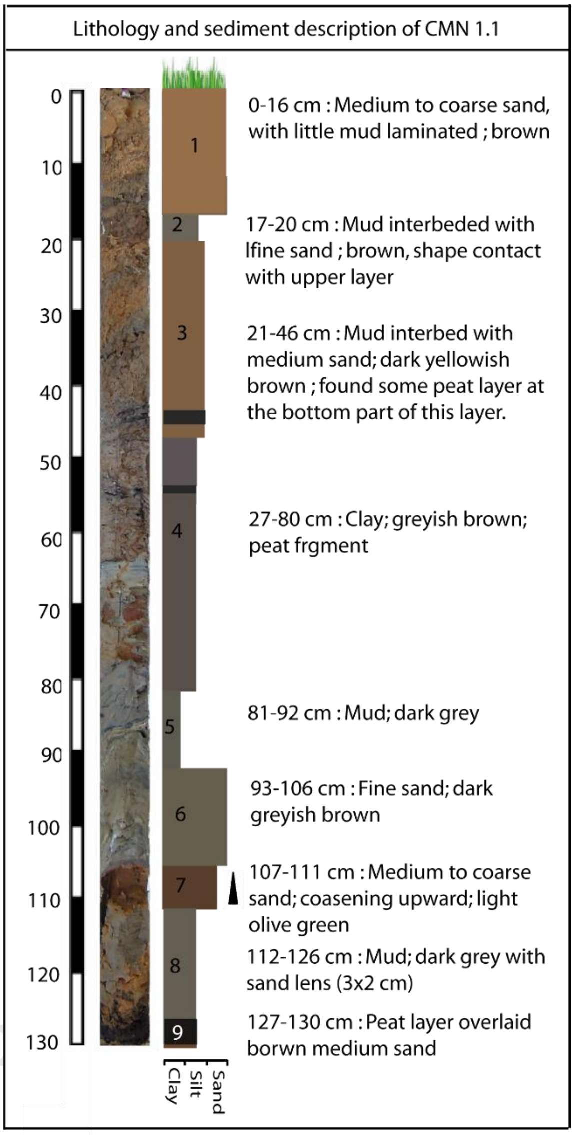
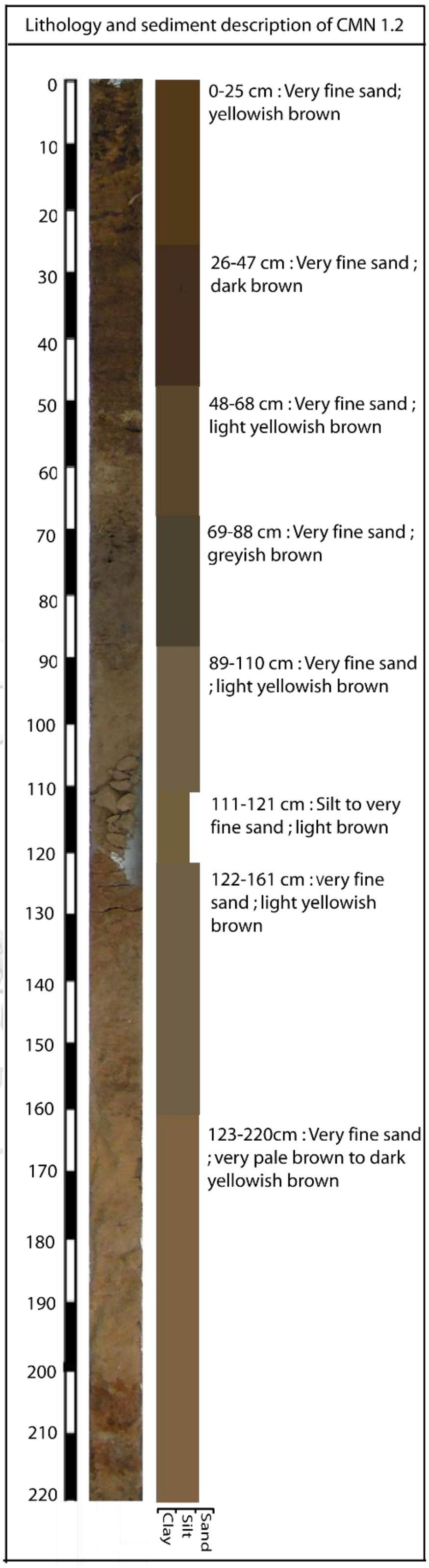
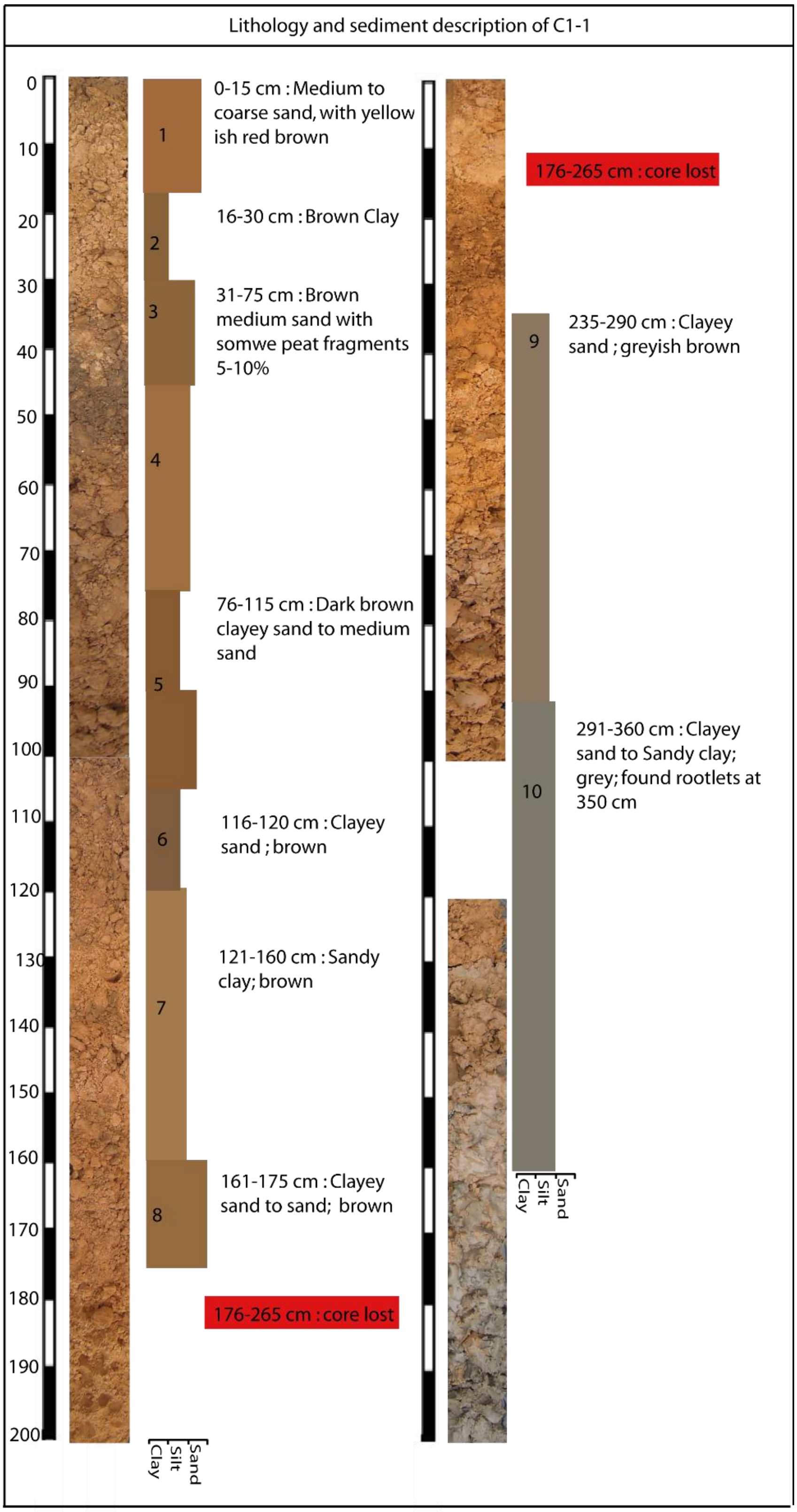
APPENDIX

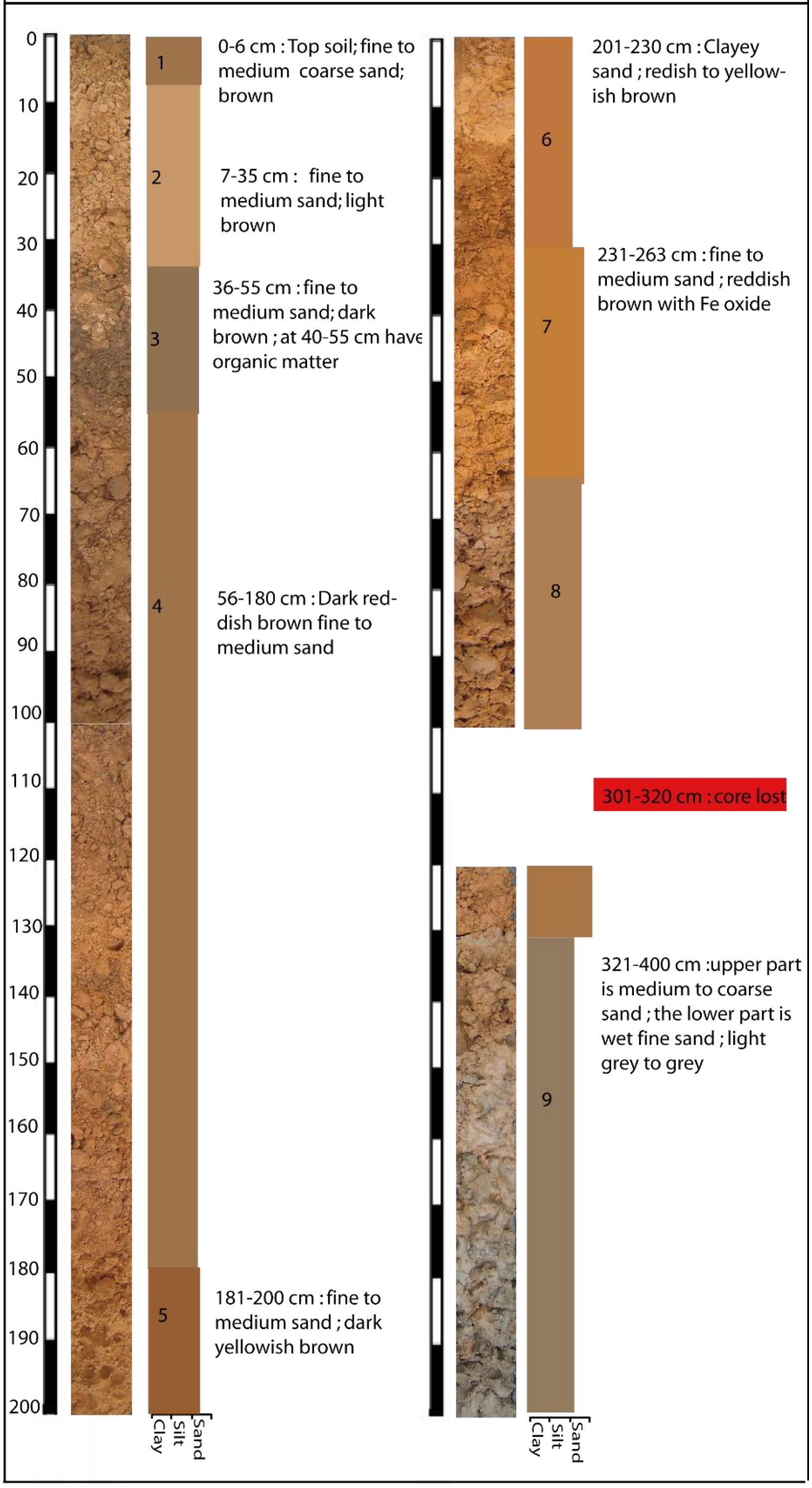
Sediment Core from hand auger and percussion drilling

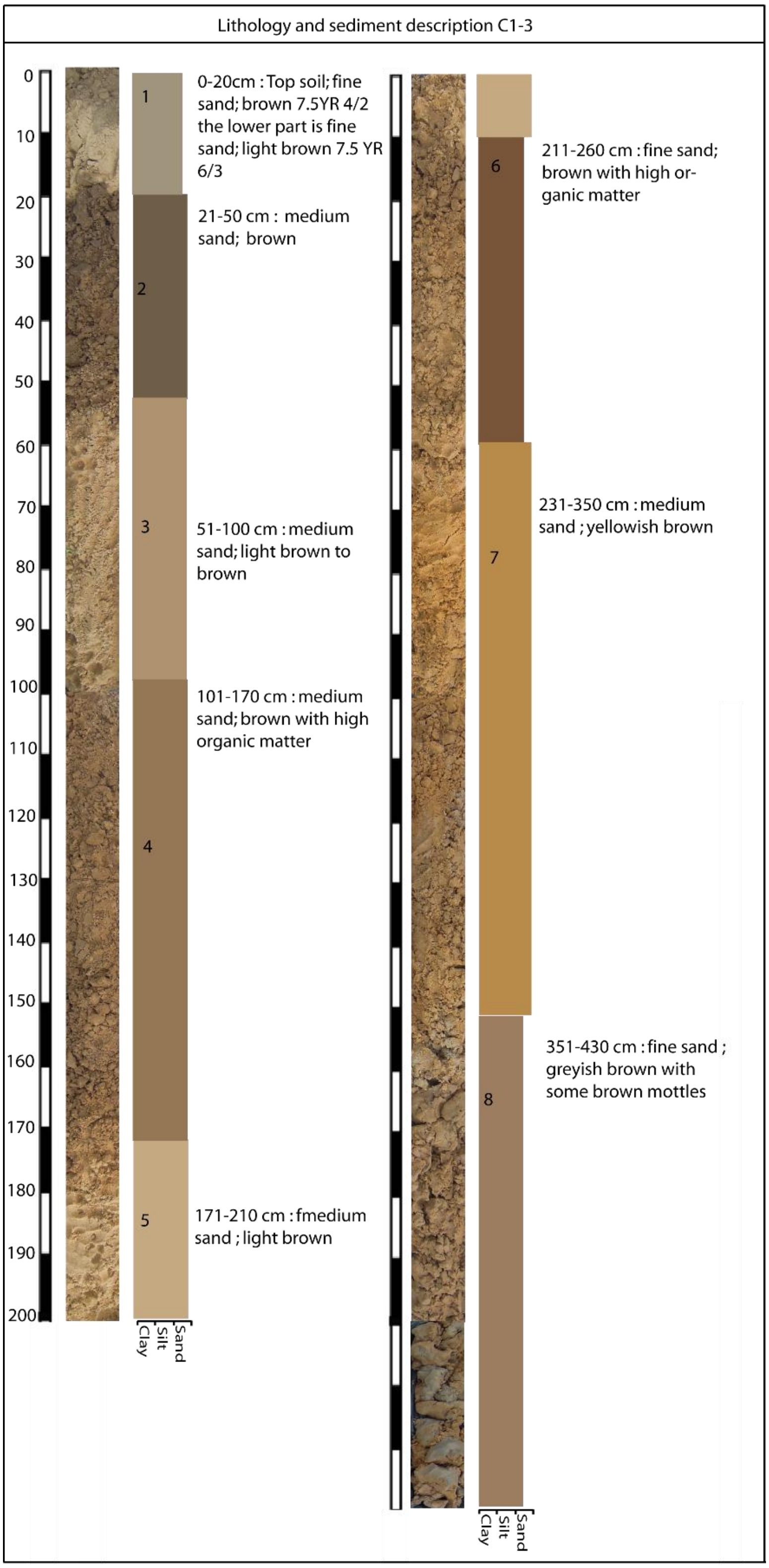


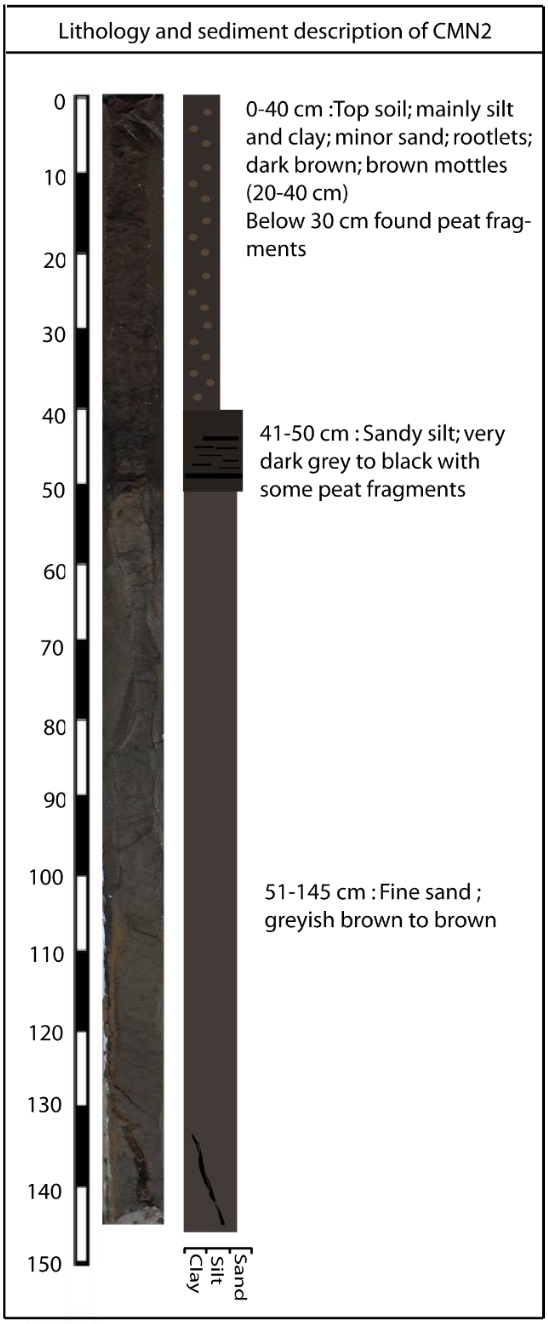

Lithology and sediment description of CMN 1.2
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
0-25 cm : Very fine sand; yellowish brown
26-47 cm : Very fine sand ; dark brown
48-68 cm : Very fine sand ; light yellowish brown
69-88 cm : Very fine sand ; greyish brown
89-110 cm : Very fine sand ; light yellowish brown
111-121 cm : Silt to very fine sand ; light brown
122-161 cm : very fine sand ; light yellowish brown
123-220cm : Very fine sand ; very pale brown to dark yellowish brown
Clay
Silt
Sand

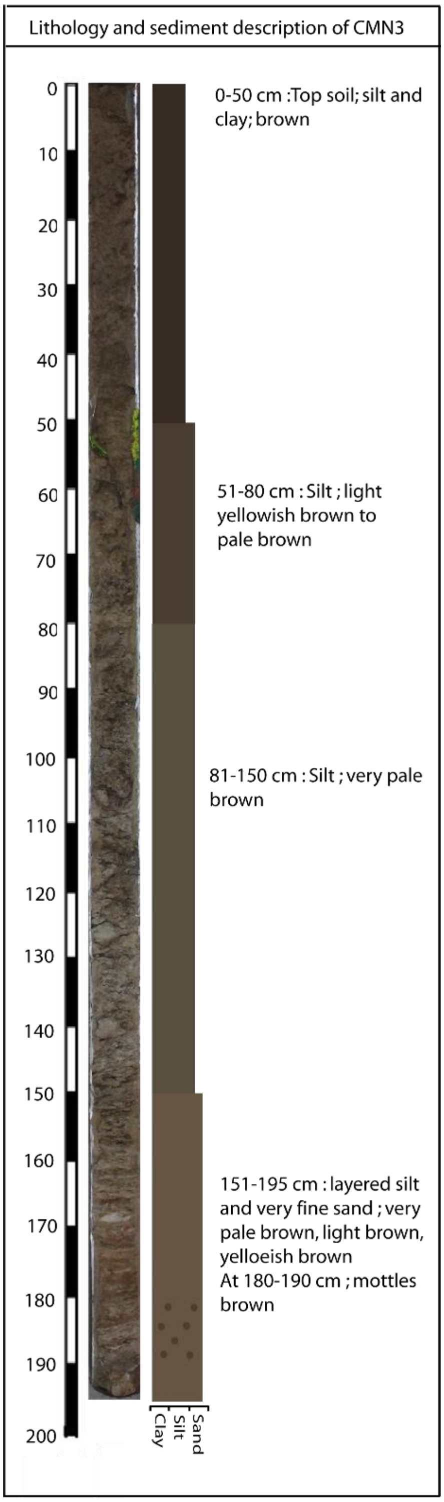

Lithology and sediment description of C1-1
0-15 cm : Medium to coarse sand, with yellow ish red brown
16-30 cm : Brown Clay
31-75 cm : Brown medium sand with somwe peat fragments 5-10%
76-115 cm : Dark brown clayey sand to medium sand
116-120 cm : Clayey sand ; brown
121-160 cm : Sandy clay; brown
161-175 cm : Clayey sand to sand; brown
176-265 cm : core lost
176-265 cm : core lost
235-290 cm : Clayey sand ; greyish brown
291-360 cm : Clayey sand to Sandy clay; grey; found rootlets at 350 cm
Clay
Silt
Sand
Clay
Silt
Sand

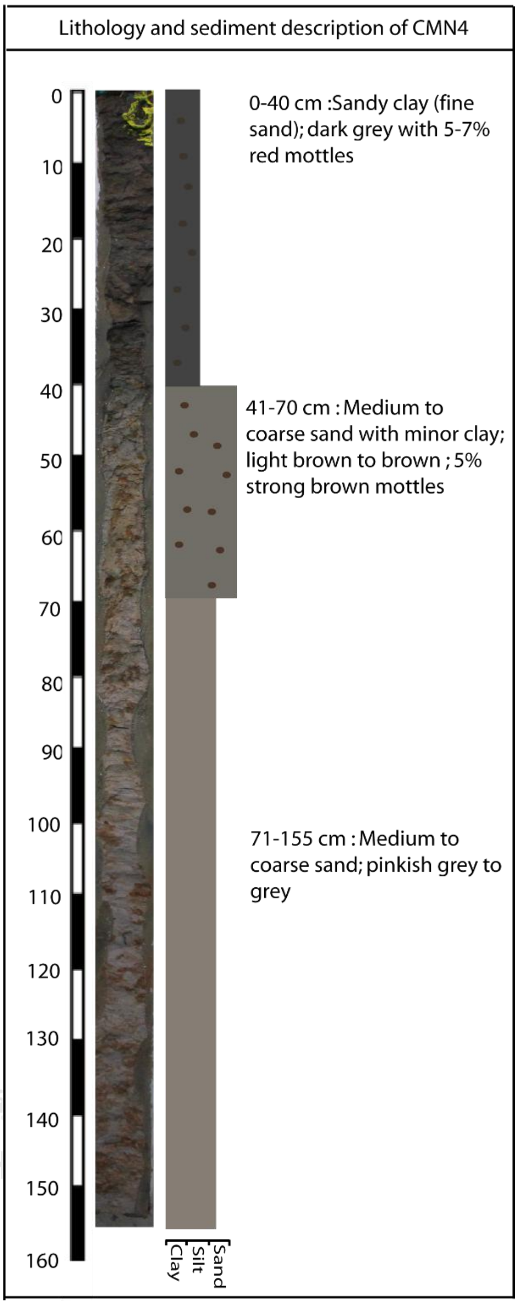
Lithology and sediment description of C1-2

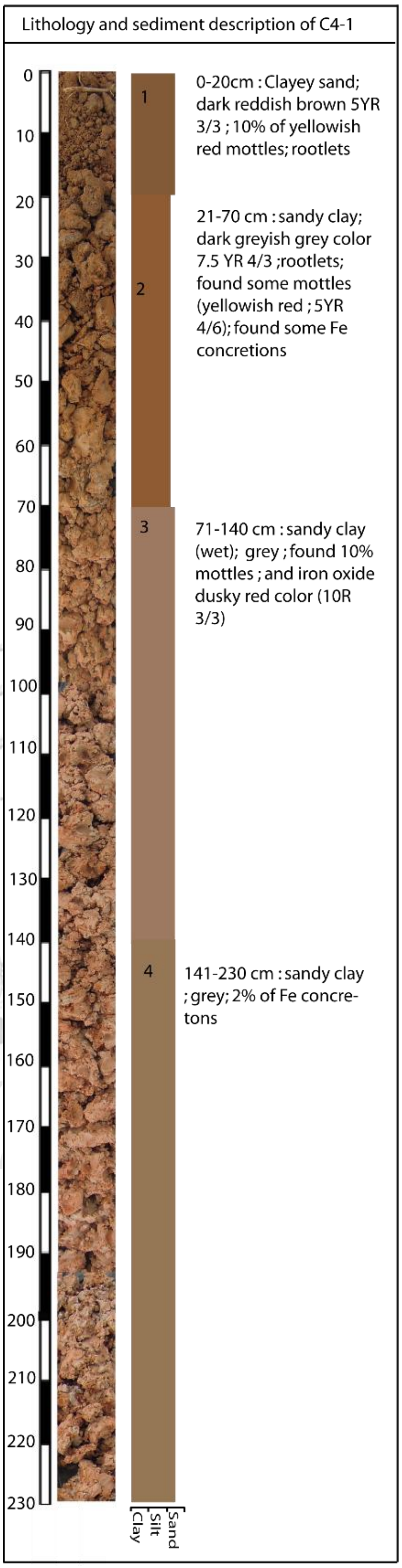



Lithology and sediment description C1-3
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
1
2
3
4
5
0-20cm : Top soil; fine sand; brown 7.5YR 4/2 the lower part is fine sand; light brown 7.5 YR 6/3
21-50 cm : medium sand; brown
51-100 cm : medium sand; light brown to brown
101-170 cm : medium sand; brown with high organic matter
171-210 cm : fmedium sand ; light brown
Clay
Silt
Sand
6
7
8
211-260 cm : fine sand; brown with high organic matter
231-350 cm : medium sand ; yellowish brown
351-430 cm : fine sand ; greyish brown with some brown mottles
Clay
Silt
Sand

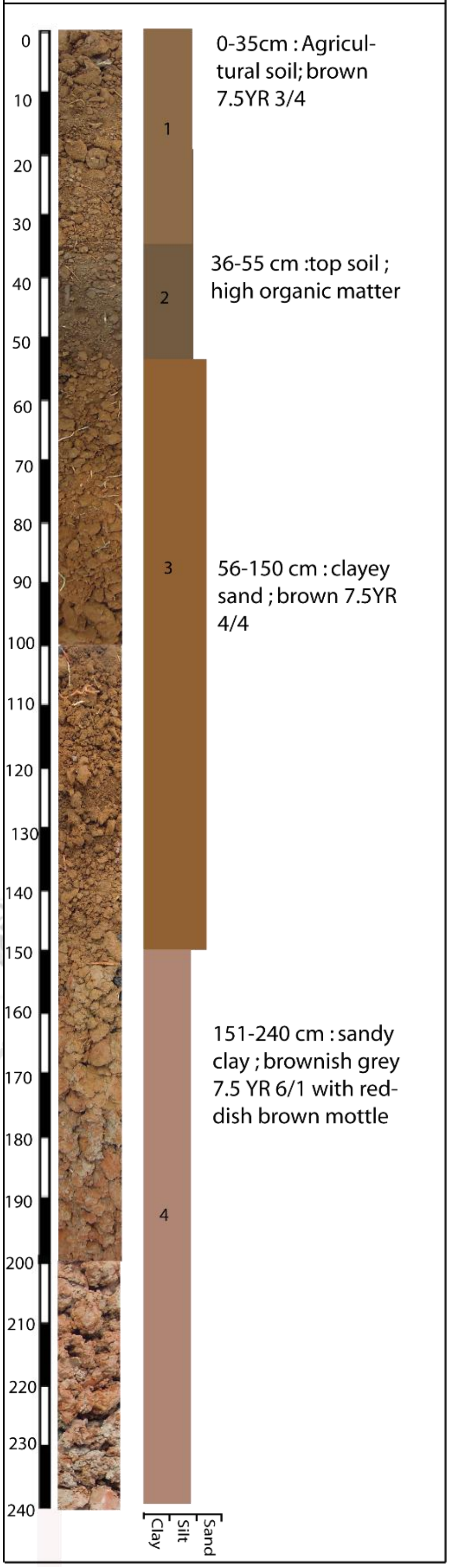

Lithology and sediment description of CMN2
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0-40 cm :Top soil; mainly silt and clay; minor sand; rootlets; dark brown; brown mottles (20-40 cm)
Below 30 cm found peat fragments
41-50 cm : Sandy silt; very dark grey to black with some peat fragments
51-145 cm : Fine sand ; greyish brown to brown
Clay
Silt
Sand

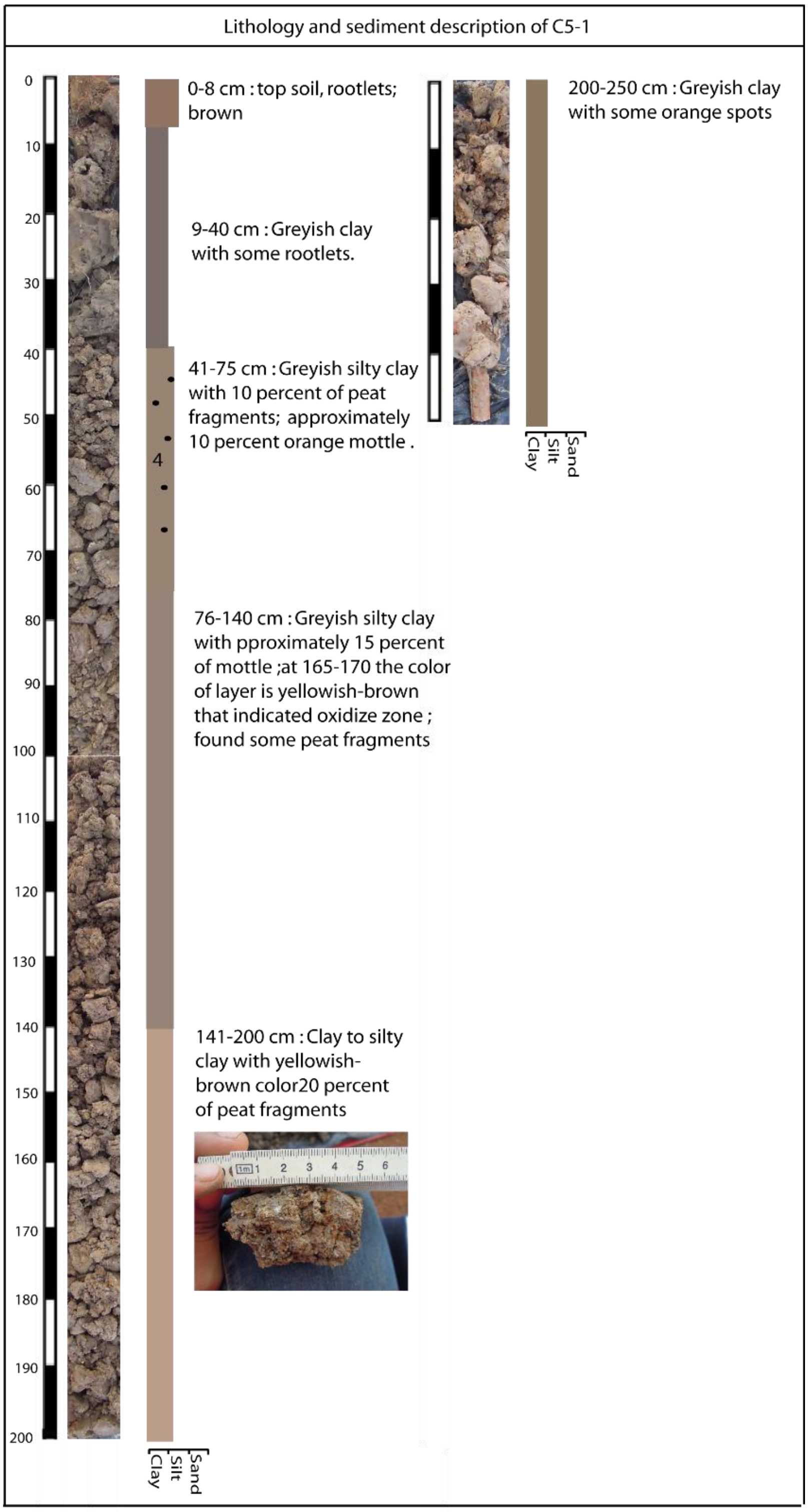

Lithology and sediment description of CMN3
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
0-50 cm :Top soil; silt and clay; brown
51-80 cm : Silt ; light yellowish brown to pale brown
81-150 cm : Silt ; very pale brown
151-195 cm : layered silt and very fine sand ; very pale brown, light brown, yelloeish brown
At 180-190 cm ; mottles brown
Clay
Silt
Sand


Lithology and sediment description of CMN4
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
0-40 cm :Sandy clay (fine sand); dark grey with 5-7% red mottles
41-70 cm : Medium to coarse sand with minor clay; light brown to brown ; 5% strong brown mottles
71-155 cm : Medium to coarse sand; pinkish grey to grey
Clay
Silt
Sand


Lithology and sediment description of C4-1
0-20cm : Clayey sand; dark reddish brown 5YR 3/3 ; 10% of yellowish red mottles; rootlets
21-70 cm : sandy clay; dark greyish grey color 7.5 YR 4/3 ;rootlets; found some mottles (yellowish red ; 5YR 4/6); found some Fe concretions
71-140 cm : sandy clay (wet); grey ; found 10% mottles ; and iron oxide dusky red color (10R 3/3)
141-230 cm : sandy clay ; grey; 2% of Fe concre-tons
Clay
Silt
Sand

Lithology and sediment description of C4-2




Lithology and sediment description of C5-1
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60
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80
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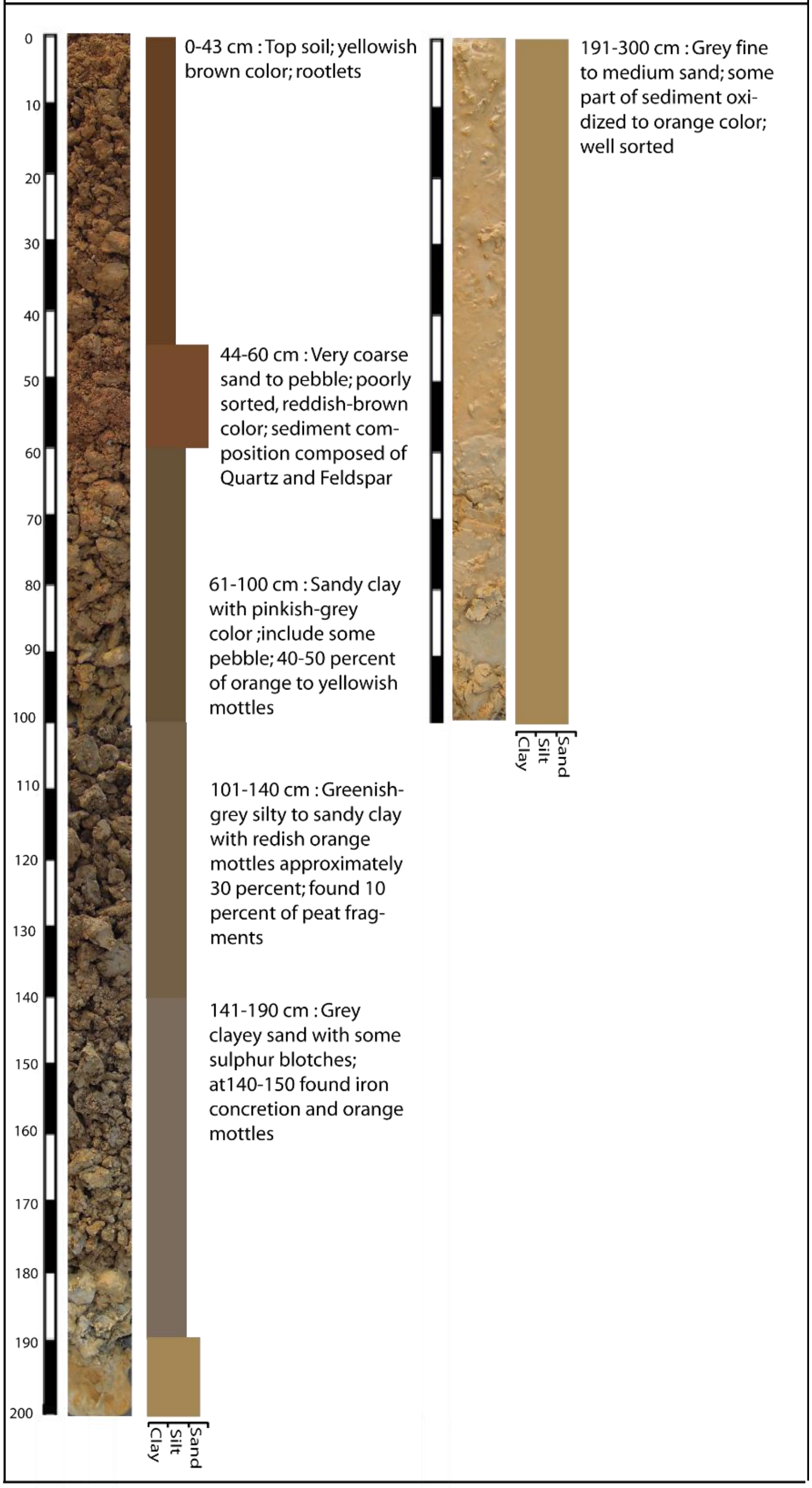
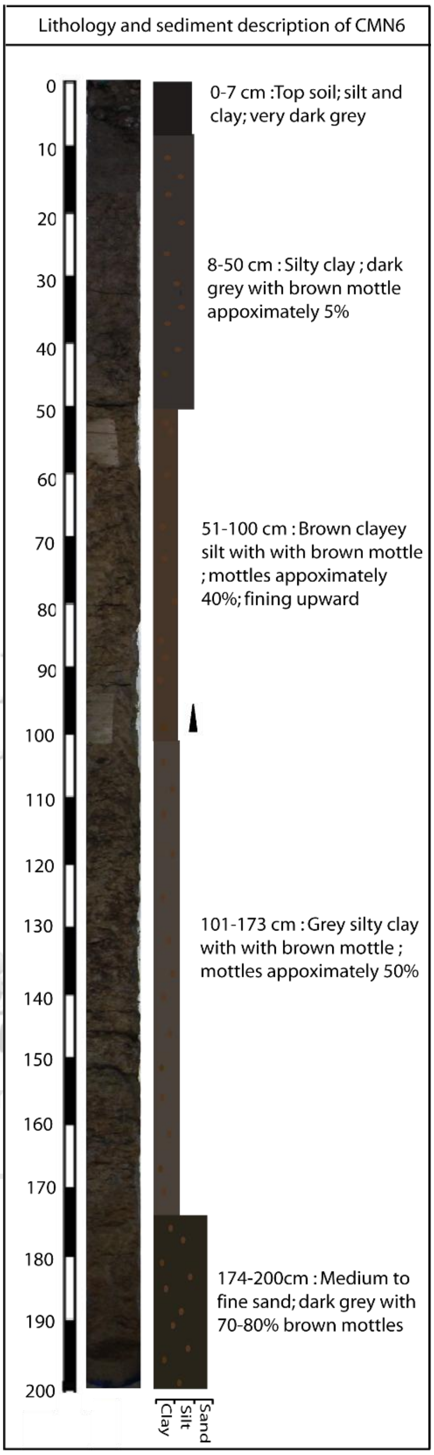
100
110
120
130
140
150
160
170
180
190
200
0-8 cm : top soil, rootlets; brown
9-40 cm : Greyish clay with some rootlets.
41-75 cm : Greyish silty clay with 10 percent of peat fragments; approximately 10 percent orange mottle .
4
76-140 cm : Greyish silty clay with pproximately 15 percent of mottle ;at 165-170 the color of layer is yellowish-brown that indicated oxidize zone ; found some peat fragments
141-200 cm : Clay to silty clay with yellowish-brown color20 percent of peat fragments
Clay
Silt
Sand
200-250 cm : Greyish clay with some orange spots
Clay
Silt
Sand

Lithology and sediment description of C5-2




Lithology and sediment description of CMN6
0
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100
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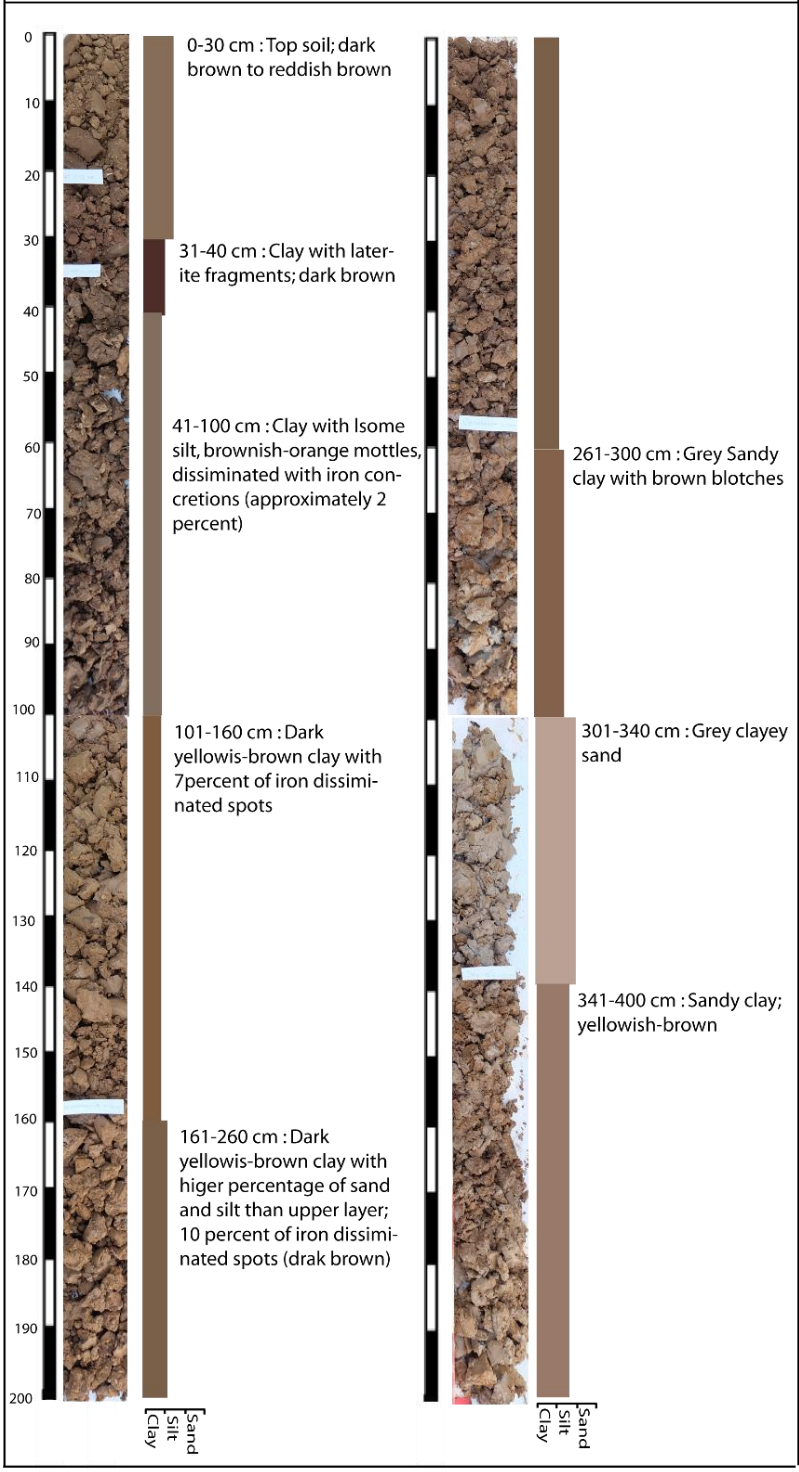
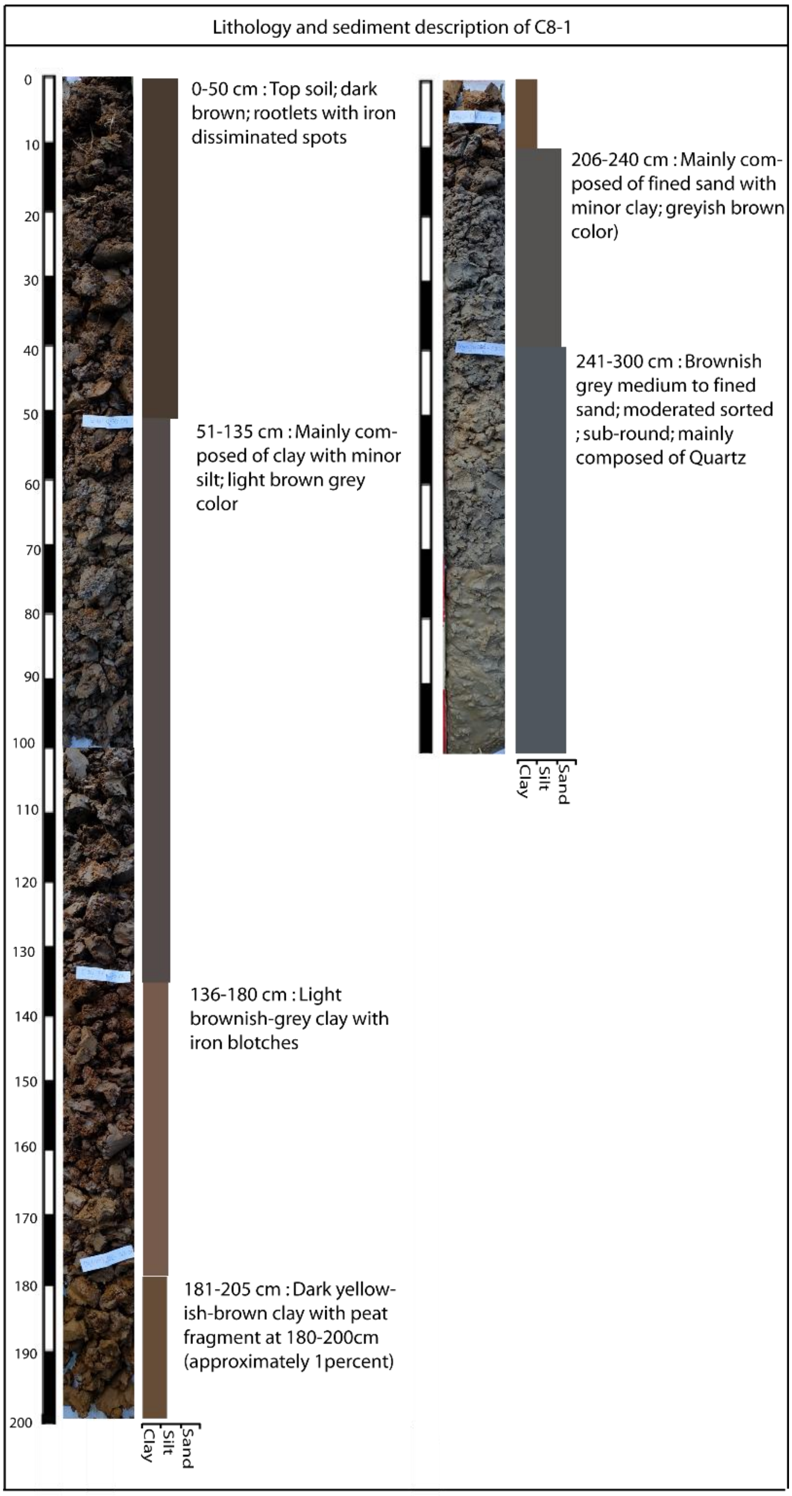
140
150
160
170
180
190
200
0-7 cm :Top soil; silt and clay; very dark grey
8-50 cm : Silty clay ; dark grey with brown mottle appoximately 5%
51-100 cm : Brown clayey silt with with brown mottle ; mottles appoximately 40%; fining upward
101-173 cm : Grey silty clay with with brown mottle ; mottles appoximately 50%
174-200cm : Medium to fine sand; dark grey with 70-80% brown mottles
Clay
Silt
Sand

Lithology and sediment description of C7-1




Lithology and sediment description of C8-1
0
10
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30
40
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60
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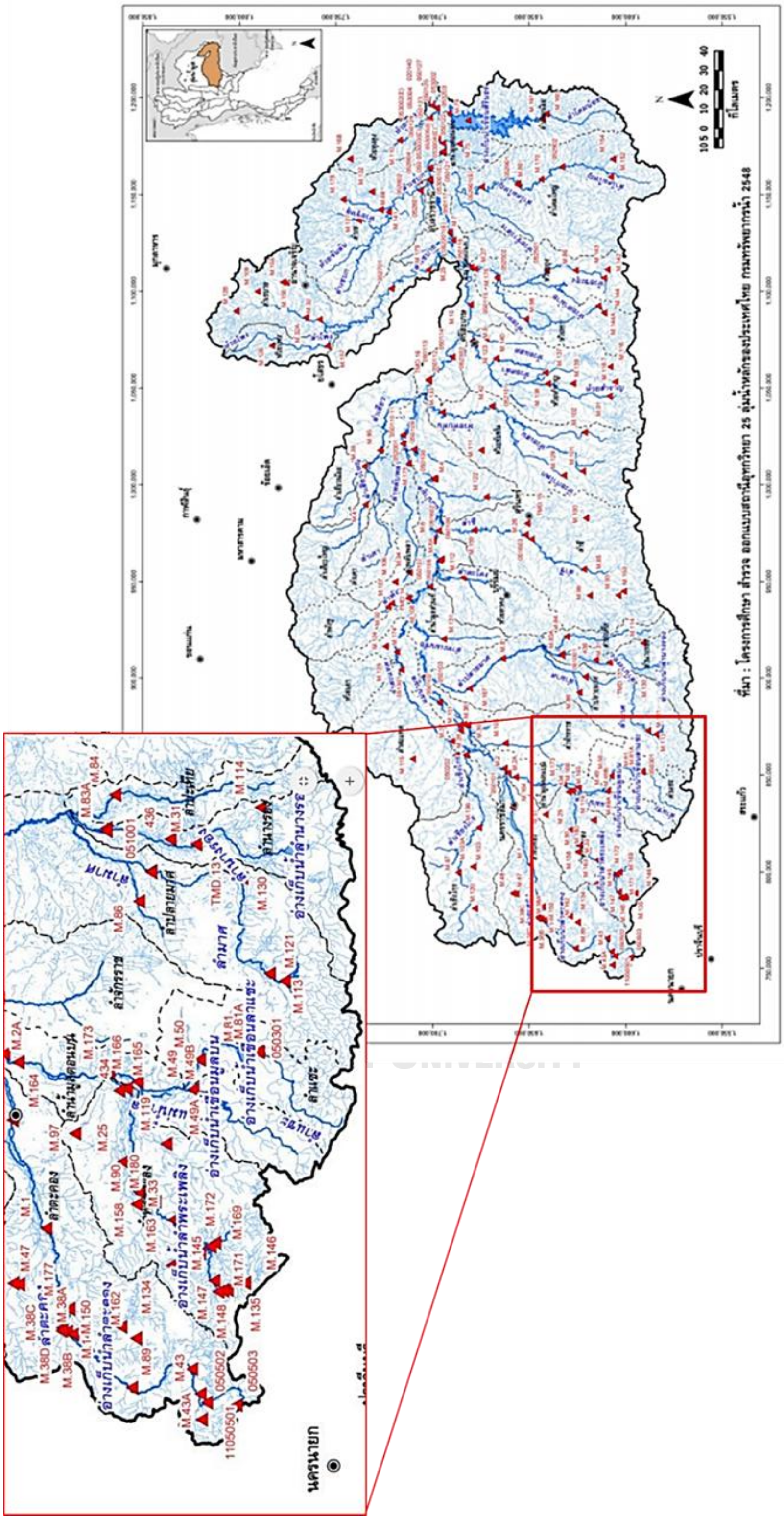
100
110
120
130
140
150
160
170
180
190
200
0-50 cm : Top soil; dark brown; rootlets with iron dissiminated spots
51-135 cm : Mainly composed of clay with minor silt; light brown grey color
136-180 cm : Light brownish-grey clay with iron blotches
181-205 cm : Dark yellowish-brown clay with peat fragment at 180-200cm (approximately 1percent)
Clay
Silt
Sand
206-240 cm : Mainly composed of fined sand with minor clay; greyish brown color)
241-300 cm : Brownish grey medium to fined sand; moderated sorted ; sub-round; mainly composed of Quartz
Clay
Silt
Sand

Locations of water station M 49 (the Mun River watershed)



Locations of water station M 49 (the Mun River watershed)

VITA

Miss Parisa Nimnate was born on 26th November 1988, at Kanchanaburi Province. She has got bachelor degree of Geoscience program from Faculty of Science, Mahidol University in 2009. She obtained the scholarship for M.Sc. and Ph.D. (Science Achievement Scholarship of Thailand) carried further study on master program on Geology, Department of Geology, Faculty of Science. Chulalongkorn University in 2010, and she specialized in coastal geomorphology, sedimentology and TL/OSL dating. After she graduated in 2013. She continued studied on doctoral program (geology) in the same place. For doctoral dissertation, she focused on fluvial geomorphology, sedimentology and shallow geophysical survey (GPR and resistivity surface). She attained an exchange Research Student Position from Japan Student Services Organization (JASSO), so her year in Japan was a very educational experience. Moreover, she also have been getting a meanuseful experience during working her part-time job as special lecturer in Geoscience program, Mahidol University, Kanchanaburi Campus.