ธรณีสัณฐานของทางน้ำในช่วงระยะเวลา 30 ปีของแม่น้ำมูล ในพื้นที่ฝั่งตะวันตกของจังหวัดบุรีรัมย์

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FLUVIAL GEOMORPHOLOGY DURING 30 YEARS OF THE MUN RIVER, WESTERN PART OF CHANGWAT BURIRAM

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Earth Sciences
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ประภาวดี ศรีสุนทร : ธรณีสัณฐานของทางน้ำในช่วงระยะเวลา 30 ปีของแม่น้ำมูลในพื้นที่ฝั่งตะวันตกของจังหวัดบุรีรัมย์ (FLUVIAL GEOMORPHOLOGY DURING 30 YEARS OF THE MUN RIVER, WESTERN PART OF CHANGWAT BURIRAM) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ศ. ดร. มนตรี ชูวงษ์, 121 หน้า.

แม่น้ำมูลเป็นแม่น้ำสาขาสำคัญสายหนึ่งของแม่น้ำโขงและเป็นที่รู้จักในด้านความซับซ้อนของทางน้ำโค้งตวัด ธรณีสัณฐานของทางน้ำที่เกิดขึ้นล้วนเป็นผลมาจากการกวัดแกว่งของแม่น้ำและการไหลเป็นเกลียวของน้ำในทางน้ำ ทำให้ทางน้ำมีการเปลี่ยนแปลงตามช่วงระยะเวลา ธรณีสัณฐานของทางน้ำที่แตกต่างกันตามช่วงระยะเวลาสามารถศึกษาได้จากการแปลภาพถ่ายทางอากาศ แผนที่ และภาพถ่ายดาวเทียม การวัดความแตกต่างของธรณีสัณฐานของทางน้ำสามารถทำได้โดยใช้ตัวบ่งชี้ทางธรณีสัณฐาน ในทางการศึกษาการเปลี่ยนแปลงของทางน้ำ ตัวบ่งชี้ทางธรณีสัณฐานที่ใช้ ได้แก่ ดัชนีการโค้งตวัด (SI) รัศมีความโค้ง (RC) และความกว้างของทางน้ำ (W) ทั้งยังสามารถนำความสัมพันธ์ของตัวบ่งชี้ทางธรณีสัณฐานมาศึกษารูปร่างของทางน้ำได้ต่อไปด้วย จากผลจากศึกษาทางน้ำในช่วงระยะเวลา 30 ปี พบว่า ทางน้ำปัจจุบันของแม่น้ำมูลโค้งตวัดมากขึ้น มีค่าดัชนีการโค้งตวัด (SI) เพิ่มขึ้น จาก 1.5 เป็น 1.8 ความกว้างเฉลี่ยของทางน้ำลดลงจากเดิม 72.81 เมตร เป็น 39.45 เมตร อันเนื่องมาจากอิทธิพลของการเพิ่มขึ้นของอัตราการไหล ในด้านอัตราการเคลื่อนย้ายของตะกอน ตั้งแต่ปี พ.ศ. 2519 – 2552 มีอัตราการเคลื่อนย้ายตะกอน 0.5 – 1.8 เมตรต่อปี เมื่อนำค่าของอัตราการเคลื่อนย้ายของตะกอนมาสัมพันธ์กับรัศมีความโค้งแล้วพบว่าอัตราการกัดเซาะของทางน้ำมีแนวโน้มคงที่ ในการศึกษาหน้าตัด 3 จุดในพื้นที่ศึกษา พบว่ามีชุดลักษณ์ 3 ชุด คือ Sh St และ Sl ชุดลักษณ์ทั้งหมดเป็นชุดลักษณ์ในกลุ่มของชุดลักษณ์ทราย ดังนั้นตะกอนทรายแม่น้ำมูลในพื้นที่ศึกษาจึงเป็นตะกอนทรายล้วนที่กัดกร่อนมาจากหินในชุดหินมหาสารคาม นอกจากนี้ยังมีการนำเครื่องหยั่งลึกเรดาห์ (GPR) มาใช้เพื่อศึกษาโครงสร้างใต้ดินของสันดอนทราย ข้อดีของเครื่องหยั่งลึกเรดาห์คือสามารถศึกษาภาพของโครงสร้างใต้ดินและประเมินความลึกของโครงสร้างนั้นๆ ได้โดยไม่จำเป็นต้องทำการขุดเจาะ ในการสำรวจจะใช้คลื่นแม่เหล็กไฟฟ้า (ไมโครเวฟ) มาผนวกเข้ากับทฤษฎีการสะท้อนของคลื่นเพื่อค้นหาความไม่ต่อเนื่องของชั้นตะกอน ในการศึกษาครั้งนี้ใช้เครื่องหยั่งลึกเรดาห์ความถี่ 200 เมกะเฮิรตซ์และล้อวัดระยะทำการสำรวจทั้งหมด 8 แนวจากสันดอนทราย 2 จุดในพื้นที่ศึกษา จากการศึกษาสามารถแบ่งสัญญาณออกได้เป็น 8 ชุดลักษณ์เพื่อแสดงความหลากหลายของโครงสร้างที่พบ อาทิ โครงสร้างการสะสมตัวในทางน้ำ โครงสร้างการสะสมตัวด้านข้าง และชั้นทราย เป็นต้น ผลจากการสำรวจโดยเครื่องหยั่งลึกเรดาห์ชี้ให้เห็นว่ามีโครงสร้างของธารประสารสายอยู่ภายใต้สันดอนทราย ทำให้สามารถสรุปผลได้ว่าสันดอนทรายในพื้นที่ศึกษามีการพัฒนาตัวมาจากสันดอนทรายกลางแม่น้ำ

ภาควิชา ธรณีวิทยา	ลายมือชื่อนิสิต ....
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PRAPAWADEE SRISUNTHON: FLUVIAL GEOMORPHOLOGY DURING 30 YEARS OF THE MUN RIVER, WESTERN PART OF CHANGWAT BURIRAM. ADVISOR: PROF. MONTRI CHOOWONG, Ph.D., 121 pp.

Mun River is a very crucial right bank tributaries of Mekong River which has been known for its complexity of meandering. Those geomorphology that are effected by river's movement and a helical flow are changed during a period of time. The various geomorphologies during different times can be interpreted from aerial photos, maps, and satellite images and measure the intensity of change by using geomorphic criteria calculation. The geomorphic criteria which are used to quantify river changes are Sinuosity Index (SI), Radius of Curvature (RC) and Channel Width (W). All these criteria and their relationship were used for further examine about meander geometry. As a consequence, SI of Mun River during 30 years has increasing from 1.5 to 1.8 which means the modern Mun River becomes more sinuous. The value of channel width average is decreasing from 72.81 to 39.45 m by influence of the increasing of flow velocity. The river has migration rate of 0.5 – 1.8 m/y. Normalization in migration rate and bend curvature (RC/W) revealed that erosion rate from 1976 to 2009 has a tendency to depreciate. Moreover, profiling from 3 different locations, it found lithofacies that predominated Mun River are Sh, St and Sl. Every lithofacies are identify in a sandy group. This information can prove that Mun River in study area was eroded from a pure sandy source associate with Mahasarakham formation. Also, the research was carried out by using a geophysical tool, Ground Penetrating Radar (GPR), to unveil the subaerially structure of point bars. The tool is a non- destructive geophysical technique that invented for shallow subsurface survey. Not only it can explore underneath earth without penetrate and drill to the ground but also it can show image and estimates depth of subsurface object. By using magnetic wave (microwave) and reflection theory, GPR allows to record a near-continuous sedimentary structures. 8 GPR survey lines from 2 sites achieved by using 200 MHz antenna attached with an odometer based survey wheel for distance tracking. 8 GPR radar facies were recognized to expose variety of sediment characteristics e.g. channel fills, side bar deposit and sand beded. The results from GPR interpretation indicated the complexity of braided characteristic under point bars. Therefore, it can conclude that point bars have developed from mid-channel bars.

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

Page

Page

Page

LIST OF FIGURES

Page

Page

Page

Page

LIST OF TABLES

Page

LIST OF ABBREVIATION

SI	: Sinuosity Index
RC	: Radius of Curvature
W	: Channel Width
GPR	: Ground Penetrating Radar

Chapter 1
Introduction

1.1 Background

Geomorphologists have always been interested in studying meander river process. Meander is one of channel patterns that changes rapidly from time to time and has an amazing process to maintain its shape (Wohl, 2014). Meander is mainly spots in a low gradient area where a straight river was eroded in a floodplain area. Basically, erosion takes place on concave; on the other hand, deposition is affected to the convex. In low-lying area, channels are migrated by meandering process across floodplain. The rising of erosion and deposition rate can cause channel geometry unbalanced which make river increasing the sinuosity. A meander river can be described its shape as a sine-generated curve because it is not a segment of circle or a regular sinusoidal wave (Leopold, 1973). The study of meander mostly concerns with an examination of change and test a model theory for prediction a meander shape in the future (Hooke, 2007). Materials that widely used in this study field are composed of the historical map, aerial photographs and satellite image (Martha et al., 2015; Wood et al., 2008). The aims are to monitor river shape by bird eyes view and to measure true distance to get efficiently parameters (Thorne, 2002).

The interpretation from aerial photo and satellite image give a lot of information about surface change but subaerial information still mysterious. Subsurface survey mostly is a destructive method like borehole logs, coring data, out crop sample (Ekes and Hickin, 2001; Schrott et al., 2013; Słowik, 2016). There are not suitable to use in study for reconstructive paleo-environment because it demolishes subsurface structure. From this reason, geophysical method becomes admirable because it can survey with no need to penetrate the ground. Recently, the geophysical method which is favorite for shallow subsurface fluvial study is Ground Penetrating Radar (GPR). This tool uses magnetic wave and reflection theory to survey the unconformity layer of sediment. The differences between dielectric constant of the composition effected when passing energy to the ground (Jol and Smith, 1991). Hence, reflection signal which is reflected back with depth and convert from travel time (n/s) can illustrate subsurface image. The numerous papers like Vandenberghe and Overmeeren (1999), Bano et al. (2000), Sambrook Smith et al. (2006), Labey et al. (2009), Słowik (2011), Parker et al. (2013), Lejzerowicz et al. (2014) are used GPR to derive data from subsurface for profiling subsurface structure.

Mun River in Buriram is selected for this research because of its abundant meandered scar and various channel geometry. Channel here has an apparently high sinuosity and mostly still in a natural environment. Also, Mun River has a sandy bed which means it can be affected very much by erosion and deposition. With high rate of erosion and deposition, it can also be monitored in a short period of time. However, the study of meandering river in terms of its morphology and geometry from the Mun River is still lacking. Previous researches carried out from Mun River consisted of hydrological study (Akter and Babel, 2012), paleontology (Duangkrayom et al., 2014), paleoclimatology (Boyd and McGrath, 2001; 2008) sedimentology Loffler et al. (1984) and archeology (Hillson, 1996; King et al., 2013). Moreover, the results from interpretation of aerial photo and satellite image make Mun River interested for study subsurface. Due to the complexity of landform, Mun River subsurface may also present complex of lithofacies. The lithosfacies of Mun River in this study gain by interpretation of GPR signal and profiling outcrop. Therefore, this work is the first to describe the development of meander in the western part of Mun River at Buriram, especially focusing on 1976, 2006 and 2009 geomorphic criteria and subsurface structure. The expectation is not only to know factors controlling the change of river course, but also to understand river behavior.

1.2 Research Objective

1. To compare geomorphology change of Mun River during 30 years (1976, 2006 and 2009) from aerial photos and satellite images in 3 periods.

2. To apply a geophysical tool, Ground Penetrating Radar (GPR), for study Mun river subsurface profile in the study area.

1.3 Scope of the Study

This research purpose to determining geomorphology change of Mun River in western part of Changwat Buriram. The study area is cover about 144 square kilometer. The images and photos that used to interpretation are only from year 1976, 2006 and 2009. Based maps for define position and ground control point are from map L7018 by Royal Thai Survey Department and Google earth.

1.4 Benefits

1. Change of geomorphology of Mun River that is comparing from aerial photos and satellite images during 30 years (1976, 2006 and 2009).

2. Subsurface profile that surveys by using Ground Penetrating Radar (GPR).

Chapter 2
Literature Review

2.1 Geomorphology of Meandering and Low Gradient Landforms

A river is one of the most dynamic system that brings lots of impact to earth surface. Each of it has its own characteristic which is depend on many factors such as elevation, rock element, a stream bed, discharge and sediment. Normally, river always has an origin from the mountain then fall to the lower elevation as a waterfall. Hence, the cross section of the river at the beginning is like a ‘v’ shape. After that, water is moving gradually to the low elevation following the gravity force. When a lot of small channels reach at one of the based elevation, they are combining to be a river. The point that combined all tributaries is called collecting system (Choowong, 2011). Elevation plays a big important role to a river shape. When the river has a high gap of elevation, it makes river become small but has a high rate of erosion in vertical way. Both discharge and sediment are moving fast forward. So, the river shape is quite straight or low sinuosity. Opposite to a river in low elevation, it has much more curved. Because of elevation remained steady, erosion effects much more in horizontal way. Channel is expanded wider than deeper. From this reason, it makes a river has curves and bends.

As it shown from the top view of a river photo, geomorphology of channel patterns can categorize to three types. The first one is a braided. (Figure1a) A bank of a braided channel is easily to erode and has hugely variable discharge. Water drain freely following a slope. Sediments which are transport through the channel get deposit and transform to bars or islands. Hence, form the top view, a braided pattern can see as a greatly network of a stream. On the other hand, in the flooding time which is a channel become a bank full, bars and islands are submerged. This pattern regularly appear at a highland area and a glacial environment where channels depth is dramatically decrease. Second type of channel pattern is a straight channel. It can see clearly from the top view as a single channel that direct or has a gentle curved.

(Figure1b) This pattern is considered as the most low sinuosity pattern. The geometry of channel is symmetry. So that, it means channel has an even rate of erosion and deposition. Straight channel pattern is rarely found in nature. Mostly, this pattern is a man-made construction e.g. waterway and dam. The last pattern is a meandering channel. It is mainly spots in a low gradient area where a straight river was erode in a horizontal way. Erosion take place on the outer bank and deposition on the inner bank. So, channels are influenced to migrate forth and back across the flood plain. Because a meander river consider as a highly sinuosity river, typically it found a cut-off and a channel direction change. Main channel's position can change too and effect to adjust the shape itself. In short, there are 3 channel patterns, a straight, a braided and a meander, each patterns have their own characteristic.

Focusing on a meander river process. According to above paragraph, erosion and deposition play a big important role in this landform. Because both of processes make river to be a meander. The more erosion and deposition rate, it will be more sinuous. Beginning with a straight river, erosion and deposition rate are balanced. Channel geometry too, it is balanced perfectly as a "U" shape. Time passed, sediment that is transported along a channel is deposit at low energy region. At the same time of deposition happened, erosion is working at the opposite side because of high water velocity. A low energy region is always an inner bank which is called "convex" as well as a high energy region is always at an outer bank and called "concave". Sediment at high energy area is not sink to the riverbed but it is carrying by the turbulence and help to erode a river bank. Hence, channel geometry in a meander river is changed. At the riverbed one side is lower than the other side. This makes river be a sinuous. A meander river can describe as a sine-generated curve. Its shape is distinctive because it is not a segment of circle or a regular sinusoidal wave (Leopold, 1973).

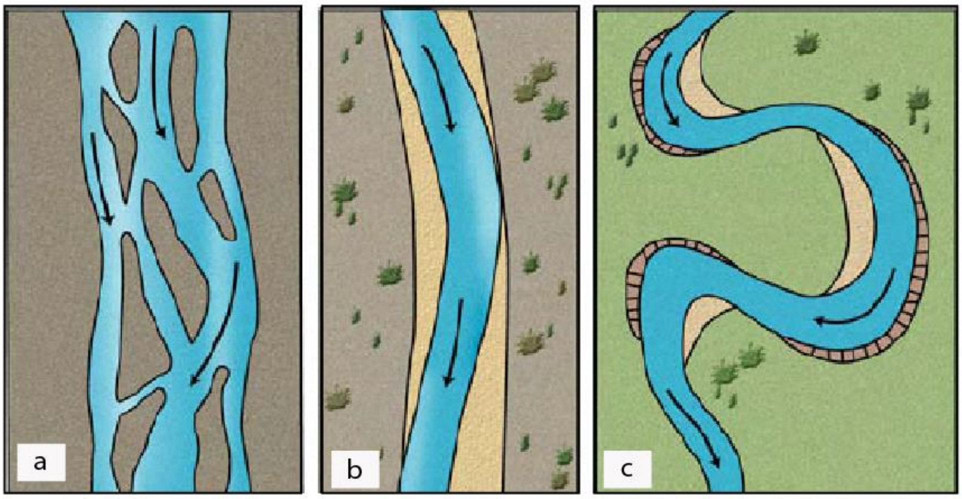


Figure 1 Patterns of River Channel (a) Braided pattern (b) Straight pattern (c) Meander pattern (Reynolds et al., 2007)

Low gradient landform is a landform that cause to form meander. The geomorphology from this landform can classify to 4 types which are oxbow lakes and meander scars, a floodplain, a river terrace and a point bar. (Figure3) Each of these has their own distinguished character.

First type of low gradient landform is oxbow lakes and meander scars. They are the result from river movement toward a landscape. Oxbow lake is a remnant of river which had been a river channel. From the top view, it can see as a depression. Mostly, oxbow lakes shape like a half moon. The process of forming an oxbow lake is start from a river has a highly sinuosity. At the perpendicularly bisect point, it was getting close to each other from both side. Erosion process takes place to cut off. The main channel is back to a straight pattern again and leave the curve behind. The new curve still fills of water but do not connect to a river. This close system makes it becomes a lake. When the oxbow lake is dry, it called meander scar. Generally, mender scar is dry but still can see it as a ridge because of shape and lines of vegetation. Both oxbow lakes and meander scars is useful in the study about a meandering river because it can be a good evidence for tracking a change trace of a river. Typically, oxbow lakes and meander scars of a modern river have a shape relate to a present channel and found nearby. In contrast, oxbow lakes and meander scars which are found in distance and has a difference shape can be a palaeo-channel.

Secondly, it is a floodplain. Floodplain laid down by river and can preserve alluvial deposition. Generally, floodplain is considered as a gentle area beside the main channel. It formed by bank erosion of meander of the river. During river travel to downstream, normally water can erode the bank and might flood out of the channel. This process can formed the floodplain by leave sediments which water cannot carried toward downstream behind. From this reason, floodplain is accumulating unconsolidated sediments like sand, gravel, silt and clay (Goudie, 2004). Furthermore, floodplain can present the area where the water would be cover out of the channel during flooding period. Also, on the floodplain it can find the numerous of geomorphologies which are effected by the river behavior. The geomorphology like meander scar and oxbow lake represent the obviously traces of river behavior.

Next low gradient landform is river terrace. It is a step-like landform which is an upland beside floodplain. (Figure3) Terrace used to be floodplain before the river adjust to the lower elevation when water was flowing in a higher elevation or the river change based level for maintain its shape or tectonic uplift. A step-like shape is created when channel erodes and cuts in to a lower land for forming a new floodplain. In the other words, terrace is a remnant of the former floodplain (Blum and Törnqvist, 2000). Hence, it found sediment like presented on the floodplain. Generally, terrace can divide to 4 types which are terrace are a fill terrace, a nested-fill terrace, a strath terraces and a fill-cut terrace. The fill terrace is a common format of terrace (Bull, 1990). It is formed by a depositional process when the stream valley has an aggradation event. In that period, the floodplain was forming and occurred an incision of the channels after leaving the floodplain (Ritter et al., 2011). Another type of terrace is a nested-fill terraces. This type was also forming because of a depositional process. The alluvium filled and incised many times in the same valley. The sediments which was filled in the process come from different sources. Third type of terrace is a strath terraces. This one is different from the two earlier types because of it formed by an erosion process. When the river cut in to the bed rock, it expanded the valley and created the new floodplain below. A strath terraces may also occur because of local or region tectonic uplift and climate change or change in bed rock type (Burbank and Anderson, 2001). The last one is a fill-cut terrace or cut-in-fill or cut terrace. It is another terrace which is formed by an erosion process. A fill-cut terrace is quite similar to a fill terrace but it originates from the erosion of the valley alluvium deposited and followed by the floodplain incision. The sediments from the erosional process fill terraces form along the valley walls. The upland of terrace in valley fill is like a fill-cut terrace. The lower remain terrace are cut terraces (Larson et al., 2015).

Last type of low gradient landform is a point bar. It is a result of sediment collection in a meandering river. It is a general geomorphological feature of a meander bend. The formation of a point bar associated to a helical flow. This can cuts the convex outer bend and deposits sediments at the concave part of the inner bend (Allen, 1965; Bhattacharyya et al., 2015). From the reason of sediments accumulation, a point bar mostly stands at the convex (inner) side of the river. A point bar width considered as the indicator of meander growth intensity and migration. The rate of migration can be calculate from the area of scroll bar which is a minor unit change in a point bar growth progression. The difference of a point bar area lead to the study the change of a river and river behavior. When a point bar become wider, it is an opportunity of channel cutting across at the inner scroll bar. This process can create a chute cutoff and it can become an inner channel along with an active main channel. The flow in this channel can has a potential to cut off. The chute channel can be link to high stream powers, abundant bed material loads, erodible banks and high rates of lateral migration (Lagasse et al., 2004). Furthermore, a point bar is categorized as a macroform in bedforms hierachrchy. Regrarding to Jackson (1976a), he suggests that various bedforms has 3 classes, microforms, mesoforms and macroforms, which are distinguished by scale and the time of span existence. Microfrom is ripples dominated by flow at the inner part of a turbulent boundary zone. Mesoforms refers to dunes, transverse bars and linguoid bars and it dominated by flow at the out of boundary zone. Also, mesoforms structure can be found certainly overlie on Macrofrom. Macroforms is a largest bedforms like point bars, braided bars and unit bars. This scale of bedform relatives to geomorphology, environment and change in fluid-dynamic regime.

In geomorphology work, point bars divided to 3 types which are tail bars, chute bars and scroll bars (Kleinhans and van den Berg, 2011). Generally, tail bars are not related to river flow natural conditions. It is formed when discharge cannot flow smoothly because of an obstruction. Next type is chute bars. Mostly, chute bar found at downstream where the end of chute channel is. Fielding and Alexander (1996) state that chute bars is an outcome of highly stream power. It formed during the time when current had strong power until it could flow across a point bar. The last one is scroll bars. A scroll bar can see obviously as a bundle of ridges-swales which has curves parallel to channel curvature. Those ridges always stretch cover entire of a point bar width. The succession of scroll bars can also represent the growth of point bars and channel relocation. (Figure2) However, a point bar is only a top of ice berg in the reason of river structure intricacy. There are lots of complexity internal structure, which cause by internal and external mechanisms from spatial variation, make it variety (Hooke, 2007). Especially for a fluvial sand body or alluvial suite, there are still doubt about how to simply distinguish braided and meandering. Plenty works on fluvial change study like Santos and Stevaux (2000), Skelly et al. (2003), Lunt and Bridge (2004) and Horn et al. (2012) were trying to indicate simply internal structure whether braided or meandering planform pattern. The river may adopt both pattern at the various period (Kelly, 2006).

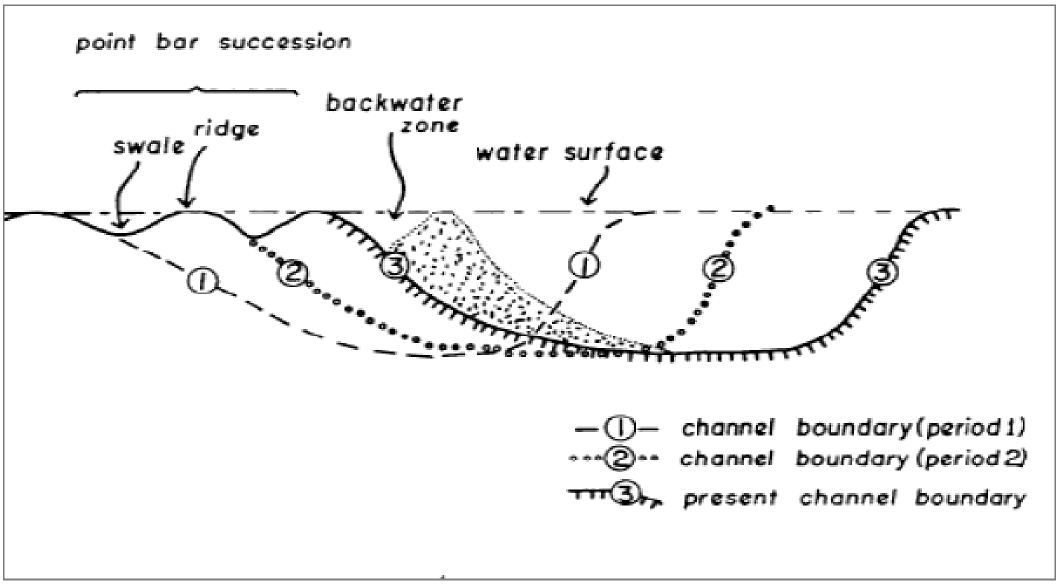


Figure 2 The Succession of Scroll Bars and Channel Relocation (Hickin and Nanson, 1975)

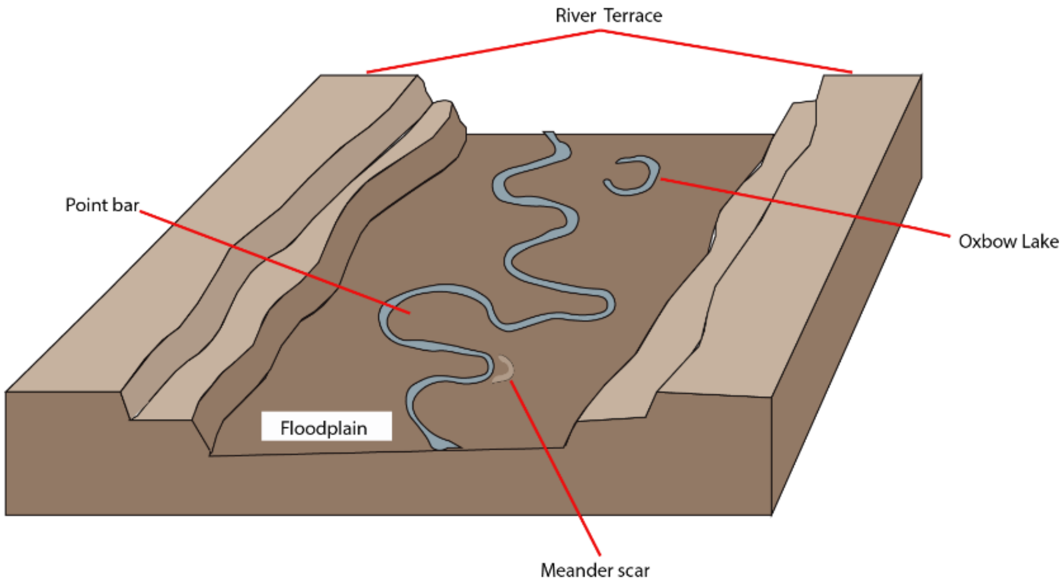


Figure 3 Geomorphology in low gradient landforms (Modified form Pearson Prentice Hall, 2005)

Modes of transformation that can occur in a meander river are expansion, translation, expansion and rotation and translation and rotation (Brice, 1974; Daniel, 1971; Ghinassi et al., 2014; Jackson, 1976a). This mode is an evidence which is related to an analyst of complexity river plan- form change. Mostly the study of a modern river change uses this mode of transformation to conclude about evolution of river bend. Each modes of transformation also represent to patterns of migration. Differences migration rate make channel change in various ways. An expansion mode is a general mode of transformation. This mode represents that the channel is stability and migration rate remain constant. The bend is increasing in a transverse way from river flow. (Figure4a) The deposition mostly at the convex side and help to increasing flow-path long. Flow path which is growth as a half circle shape becomes swales. From expansion mode, it makes river more sinuous. Opposite to an expansion mode is a translation mode. A translation mode has a basic thought as an expansion mode but flow-path is growing in the same way of the channel-belt axis. (Figure4b) The migration which is happen at the bend apex is directed the bend to down-valley. Transformation mode is not make river rise up sinuosity but remained constant. Next mode is a combination of expansion and rotation. In this mode, the migration is not only make bend expands but also rotates the bend apex away from bend axis. (Figure4c) Last mode in fluvial transformation is translation and rotation mode. This mode the bend will grow to down-valley direction as translation mode but also rotates toward channel-bend axis. (Figure4d)

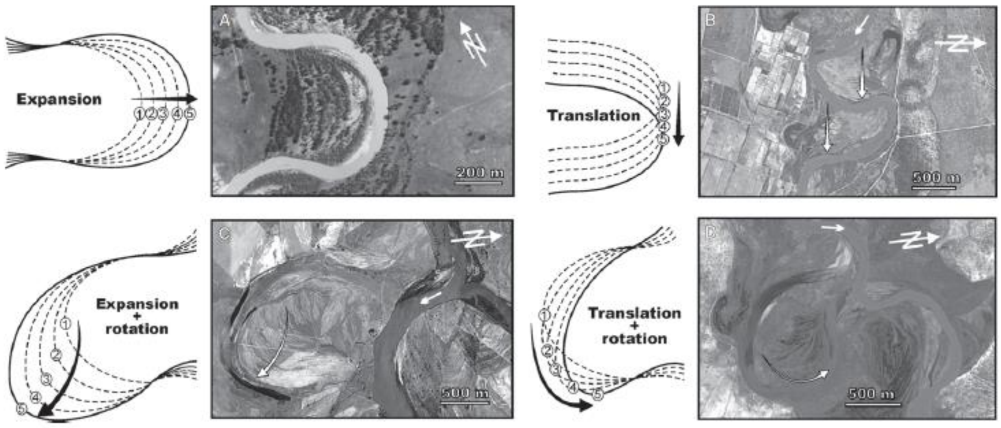


Figure 4 Mode of Transformation in fluvial process. a) Murray River, Australia b) Rio Colorado, Argentina c) Rio Negro, Argentina d) Rio Colorado, Argentina (Ghinassi et al., 2014)

2.2 Meander Migration

Studying for the historical of meandering development is difficult because of the migration. The remnants of river behavior on the floodplain such as scroll bars and meander scars was destroyed by downstream migration process. Therefore, it is quite complicated to separate and order age from entire of traces from just only visuality. However, it can use the knowledge about the principle of meander development, erosion-deposition balance and migration rate to reconstruction the forming of meander and development process.

According to Hickin (1974), the history of meander can be tracked by studying channel bend trace which exist on floodplain deposit. The meander is generally developed following 4 principles.

1. Point of channel inflection in the initial stage of meander development is fixed. The lateral migration at the channel bend during this stage occur at the principal of erosional-axis and it can decrease the radius of curvature.
2. The rate of lateral migration at the channel segment can decrease as low as a minimum number when the ration of curvature (RC) to channel width (W) or RC/W equal to 2.
3. The RC of close meander loops must effect to the each other in the opposite way. In the other word, if RC at one loop decreases, the next loop will increase. Hence, both of them have related erosion activity which cause the change in rate and direction of lateral erosion.
4. Maximum rate of concave bank erosion did not occur only at downstream of the axis of symmetry of a point bar. Many cases showed that a channel responds a critical curvature condition by eroding the concave banks on the upstream limb of a channel bend.

Leopold and Wolman (1960) state that the erosion rate at the concave could be equal to the deposition rate at the convex so the channel can be equilibrium. From this theory, if erosion balanced to deposition, width and channel cross section will be able to retain their shape. Also, the balance can make the channel cross section shape symmetric. Hence, it can assume that lateral migration makes channel balance and symmetric. In contrast, there is no case that erosion always equal to deposition. Many cases show that lateral migration is discontinue because of the external influences such as flood, discharge variation, velocity and among of sediment supply (Nanson and Hickin, 1983). Therefore, it makes channel width varies and around the balance width. Furthermore, changing of erosion rate can cause various results on bank strength and erosion-deposition cycle even it is only a short term. For example, outer bend always confront with severe erosion during flood. Meanwhile, the accretion of point bar during the flood is much slower (Nanson and Hickin, 1983). The river gains more width and decreases erosion rate at the concave for the next comparable flood form this situation. At the same time, a point bar is growing by the lateral accretion until the river is again reached equilibrium width. In conclusion, the rate of migration in a meander bend counts on the accretion rate of point bar and width adjustment.

Meander migration can estimate by using the migration rate. Migration rate is the rate of lateral migration which determined by examining the room between consecutive scroll bar and the interval time of their formation. Hickin and Nanson (1975) claimed that the rate of migration will increase if high discharge or the slope of the water level increase. From this reason, the rate of migration can represent to the paleo-environment during that time and shows development of river behavior. Migration rate can calculate by using 2 geomorphic criteria which are radius of curvature (RC) and channel width (W) of the main channel. The ratio of migration rate classified to 3 classes which referred to stage of river. If ratio is 1 to 2, the river is in the high erosion stage and may has chute or neck cutoff. Migration rate between 2.5 to 4 means that river may has bank erosion. When migration is raised to 5 or more, it declared that river has low erosion (Nanson and Hickin, 1983). The migration rate reaches to the peak when ratio is about 3 (Hickin and Nanson, 1975). Naturally, the rate of migration of new forming meander is larger than 5 which means the new born meander river has low erosion. The secondary circulation and sheer stress at the concave bank is not strong. However, the migration rate still works and its cause bend sharpen. Leopold and Wolman (1960) state that mostly the river bend in nature has the ratio between 2 - 3. Because bend tries to migrate to increase RC due to the migration rate at elsewhere is very small. This is an evidence to prove that nearest bends can effect to each other. Many cases found that if one bend increased RC, the RC of adjacent bend will decrease (Hickin, 1974).

2.3 Geomorphic Criteria

2.3.1 Sinuosity Index (SI)

Sinuosity Index or SI is the one of geomorphic criteria which is usually used for characterized the intensity of meandering. According to Brice (1964), SI is the ratio of channel length and downvalley length. Mostly, both channel length and downvalley length are measured from a loop of channel in the river. SI coefficient is divided into three periods which all mean to classify the shape of river. If the value is under 1, it means a river is almost straight. When coefficient is 1.05 but not more than 1.25, a river is sinuous. 1.25 until 2, it shows that it is a meandering river. Up to 2, it is a highly meandering. To measure SI, it needs to know channel length and down valley length (Figure5). After that, channel length is divided by down valley length. Rivers mostly adjust themselves to be a straighter path after sinuosity index values are close to 2 (Bhattacharyya et al., 2015). This is called river self-organization theory (Hooke, 2007).

$$SI = \frac{Channel\ length}{Downvalley\ length}$$

Lagasse et al. (2004) state that SI is geomorphic criteria which is used to provide information about river pattern. It is a simply way to start to define river behavior. The velocity and bank material can influence to SI value. For example, most of river that has sand as main bank material and high velocity has high SI value. The maximum of SI value in the nature can reach to 4 but rarely found. Mostly, SI value is about 1 to 2 before river change their shape to maintain the main channel. Changing the shape is cutoff, neck or chute (Hooke, 2007). SI also represents the complexity of the meandering. Li et al. (2017), suggest result from their work about migration and cutoff of meander in Tarim River in China, that lateral rate of migration not only define by local flow-sediment interaction and bank boundaries condition but also SI and planform complexity. For instance, SI value means to the different river pattern and their characteristic.

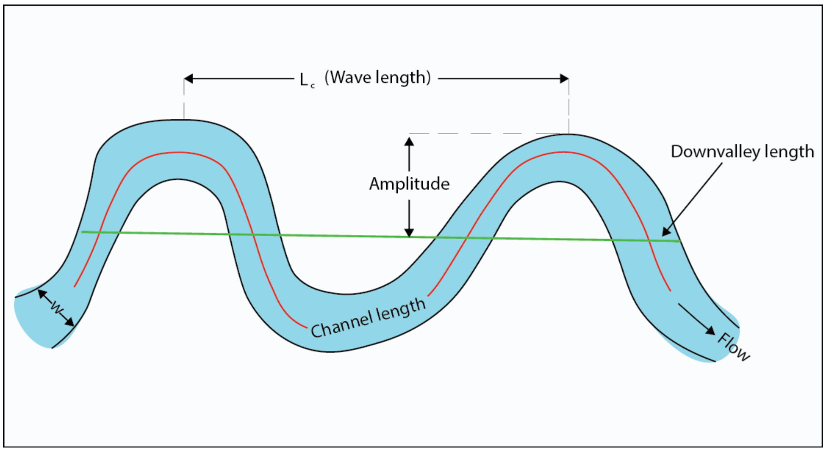


Figure 5 Sinuosity Index Theory Implied from Brice (1964)

2.3.2 Channel Width (W)

Normally, channel width refers to width of the main channel which can be a representative of the river. Due to figure 5, channel width measure form one side to another side across channel. Between two points of interest, it must be facing each other in linear. Channel width can test at any position along the channel depend on the using propose. Previous works such as Hooke (2007), Li et al. (2007) and Fisher et al. (2013), using an average of channel width from several location along the river to investigate channel planform changes. Furthermore, some hydrological models use knowledge of channel width to estimate river power per unit bed area or shear stress (Finnegan et al., 2005). Because channel width can response the effect from tectonic, climatic, lithologic and geomorphic which can reflect to channel geometry changes in the future (Fisher et al., 2013).

2.3.3 Radius of Curvature (RC)

Radius of Curvature or RC is the one of index that develop from mathematic calculation to measure a river curve. This method was developed and use in term of meander study since 1966 by among of hydrologists at U.S. Geological Survey to study potamology (Langbein and Leopold, 1966). (Langbein and Leopold, 1966) At first, it just use to calculate the curve to tell how it is different between curve to curve. RC model was developed again by Nanson and Hickin (1983). This model is quite different from the other because it is based on a measurement that derive from aerial photo. This model do not require special flow variable as input like e.g. Ikeda et al., 1981; Change, 1984; Howard, 1984 (Williams, 1986). For fluvial study, RC is used for measure the tightness of an individual meander bend. This index is unlike sinuosity because RC estimates from the outside of the bankfull channel to the intersection point of two lines that perpendicularly bisect the tangent line of each curve departure curve (NCTC, 2013). Hence, RC is similar to the radius of circle but here a curve means to a bend in a river.

$$RC = \frac{L_m K^{1.5}}{13(K-1)^{0.5}}$$

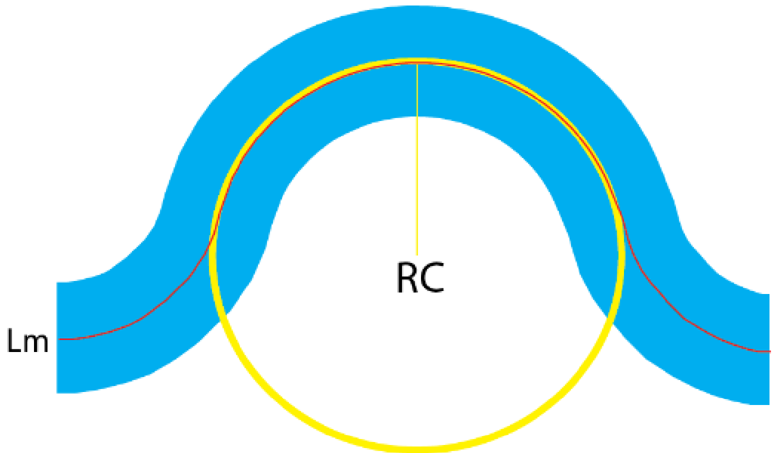


Figure 6 Radius of curvature calculation from Nanson and Hickin (1983) RC point refers to an average RC of the bend. (Modified from Williams, 1986).

The formula of RC is initially from a sine-curve as it use for describe a smooth repetitive oscillation. L_m that show in the formula refers to bend length (Williams, 1986) or stream meander length (NCTC, 2013). From the formula Lm is a distance between apex of two sequential meanders (Figure6) and K is SI of the river. RC from this formula considered as an average RC because it refer to the point at the center of meander bend. For fluvial study, RC is used for measuring the tightness of an individual meander bend and can be used to evaluate channel stability. This index is unlike SI because RC estimates from the outside of the bank-full channel to the intersection point of two lines that perpendicularly bisect the tangent line of each curve departure curve.

2.4 Lithofacies

Facies is the word that geology uses in term of explain the entire aspect of a part of the earth’s surface which specifically mean to a certain period or interval of geological time (Walker and James, 1984). This word initially introduced in 1669 by Nicholaus Steno and was used continually to explain the sequences of vertical profile of lithosphere. Hence, geologists consider facies as a study that aims to brief characteristics of a sedimentary unit. The characteristics use to define facies include sedimentary structures, grain sizes and types of composite, colour, dimentions, and biogenic content of the sedimentary rock.

Due to classification from Miall (1978, 2000), lithofacies were sorted to 3 groups which are gravelly sandy and muddy. Gravelly group has Gms, Gm, Gt and Gp. Sandy group has St, Sp, Sr, Sh, Sl, Se, Ss, Sse, She and Spe. Muddy group has Fl, Fsc, Fcf, Fm, Fr, C and P. The description of lithofacies code and interpretation from sedimentary structure present in table1.

Table 1 Description of lithofacies code and interpretation from sedimentary structure (Modified Miall, 1978)

Group	Code	Lithofacies	Sedimentary Structures	Interpretation
Gravelly	Gms	massive, matrix supported gravel	none	debris flow deposits
	Gm	massive or crudely bedded gravel	horizontal bedding, imbrication	longitudinal bars,
	Gt	gravel, stratified	trough crossbeds	minor channel fills
	Gp	gravel, stratified	Planar crossbeds	linguoid bars or deltaic groths from older bar remnants
Sandy	St	sand, medium to very coarse, may be pebbly	solitary (theta) or grouped (pi) trough crossbeds	dunes (lower flow regime)
	Sp	sand, medium to very coarse, may be pebbly	solitary (alpha) or grouped (omikron)planar crossbeds	linguold, transverse bars, sand waves (lower flow regime)
	Sr	sand, very fine to coarse	ripple marks of all types	ripples (lower flow regime)
	Sh	sand, very fine to very coarse, may be pebbly	horizontal lamination parting or streaming lineation	planar bed flow (lower and upper flow regime)
	Sl	sand, fine	low angle (not more than 10 degrees) crossbeds	scour fills, crevasse, splays, antidunes
	Ss	sand, fine to coarse, may be pebbly	broad, shallow scours including eta cross-stratification	scour fills
	Se	erosional scours with intraclasts	crudes crossbeding	scour fills
	Sse, She, Spe	sand	analogous to Ss, Sh, Sp	eolian deposits

Table1 Continue

Group	Code	Lithofacies	Sedimentary Structures	Interpretation
Muddy	Fl	sand, silt, mud	fine, lamination, very small ripples	overbank or waning flood deposits
	Fsc	silt, mud	laminated to massive	backswamp deposits
	Fct	mud	massive, with freshwater molluscs	backswamp pond deposits
	Fm	mud, silt	massive, desiccation cracks	overbank or drape deposits
	Fr	silt, mud	rootlets	seat-earth
	C	coal, carbonaceous mud	plants, mud films	swamp deposits
	P	carbonate	pedogenic feature	soil
	Fr	silt, mud	rootlets	seat-earth

The analysis of facies is a concept of grouping field evidences to identify a depositional environment. Both chemical and physical characteristics are considers in analysis and mostly they use to reconstruct the past environment. This can use to understand the condition of palaeoecology which from before and after depositional processes for further study and prediction. The reconstruct environment is possibly complicate or simple is depending on a range of setting. For example, the sand deposition process in a lacustrine environment, there sand layer give a various facies. However, the environment may variety which make a lot of confusion. It cannot directly point to the exactly past environment. The analysis could objective and based only on the recognition of the processes that formed.

According to Miall (1978), he tried to analysis the facies from a various environment and grouped the result of characteristics to create the models. He suggests that lithofacies of river deposition can classify to 6 models. 4 vertical profile models came from previous work on modern sedimentary process and ancient deposits and expanded to 6 for broadly a range of depositional variability. First model is Scott. This model dominated by massive of crudely bedded gravel mostly founded in longitudinal bars. There presents sand lenses which formed by infill of channel and scour hollows during low water (Miall, 1977). Miall erected model for proximal braided stream deposits like those braided on alluvial fan. A steep slope, an abundance of clastic debris and a high discharge were require in process of forming subaerial debris flows. Scott model found mostly at a semi – arid environment and desert area e.g. Nevada and California where long-dry period makes mechanical weathering highly influence. Secondly, it is a model called Donjek. This model can see a fining-upward cycles caused by lateral point-bar accretion or vertical channel aggradation which is dominated by sand or gravel. Generally, the cycle thickness is about up to 3 m. Moreover the thickness of cycle can reach 60 m in valley-fill sequences. Third model is Platte Model. It is quite commonly model of fluvial study and has an outstanding example like river in Nebraska, USA (Horn et al., 2012). Platte type can characterize by an abundance of linguoid bar and dune deposits (planar and trough crossbedding) (Miall, 1977). There is no well-developed cyclicity. Next is Bijou Creek type. This model characterized by the obviously planar crossbedding and ripple marks in profile which caused by horizontal lamination. Miall suggests that this model is an evidence of the flash flood during rainfall period in tropical area. Then, it is a model called Trollheim. This type proposes to explain gravelly deposits characterized by massive gravels and abundant debris flows. Mostly this type does not has an outstanding sedimentary structure because it is dominated by debris flows which has poorly sourcing like massive gravel, pebbles and course sand. All of these mix and hard to distinguish in outcrop. Thickness of debris flows may reach to 3 m. When debris flows reach to base elevation, they spread out as a lobate geometry. This flat surface consider mostly did not has channels except in the situation that the debris flows was reach the base to fill other channels. Last model is South Saskatchewan model. This is initialed for sand-dominated cyclic. It usually found in a sandy braided river. This model considers as a vary component model because it contains of variety grain of sands (very fine to coarse), silt, mud and massive rock. Also, model gives many different structure. The dominant sediment structure of South Saskatchewan model is a scour fill. It is a structure that can define by a concave-upward erosion surface that a high water velocity cut into an underneath bed and fill by coarse sand afterward.

2.5 Ground Penetrating Radar (GPR)

Due to illustrate subsurface-data ability, Ground Penetrating Radar (GPR) is widely using in geomorphology to imagine shallow stratigraphy since 1990 (Wohl, 2014). GPR principle for profiling has similarity to sonar and seismic reflection profiling but GPR is based on the propagation and reflection of electromagnetic (EM) energy (Jol and Smith, 1991). Using GPR to study shallow subsurface is concerned as a Geophysics non-destructive survey method. GPR works by using magnetic wave (UHF/VHF frequencies) and reflection theory. Magnetic wave is in microwave intensity.

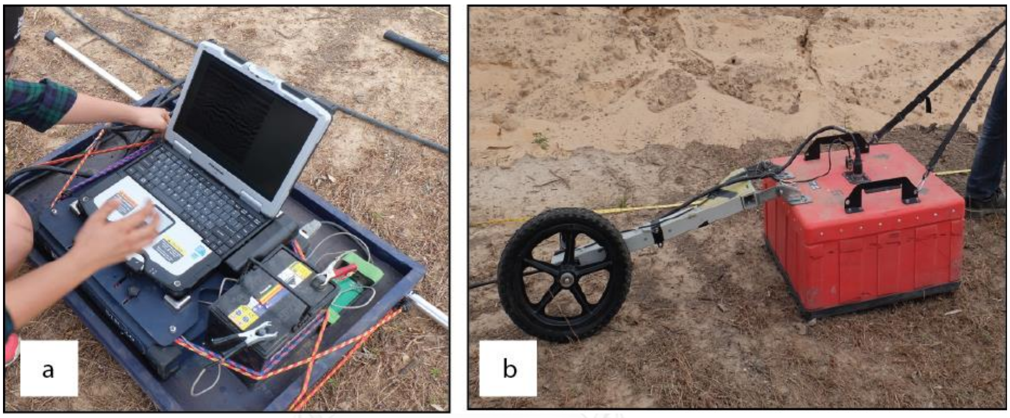


Figure 7 GPR set a) signal generator b) antenna

One GPR set must has signal generator, transmit and receive antenna. (Figure7) When GPR working, it begins from generating the signal and sending a signal to the ground. It travels to the ground as an air wave. After the wave meets the element under the ground, it reflects back to the receive antenna. (Figur8.) The receive antenna records and processes the wave as image. GPR not only records the structure underneath but also records depth of difference matter which is wave detected. Layers that show as an image after collected by survey are representing the various matter. Also signal can give related details about change in porosity, material composition and moisture content (Cassidy, 2009). The accuracy of information acquire by GPR based on antenna frequency and matter composition.

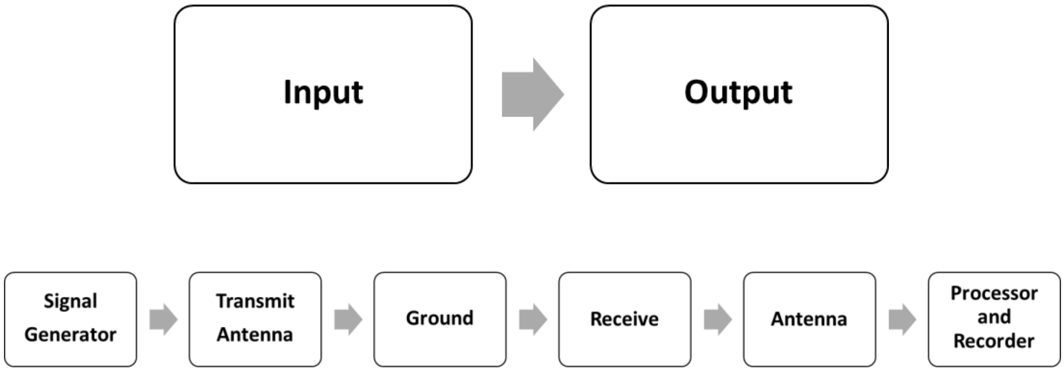


Figure 8 GPR Working Process (Modified from Alfred et al., 2008)

According to Figure 8 Antenna works as a messenger to send out and receive waves information for reflection signal. The types of antenna categorize by frequency and currently they are available from 10 MHz to 1 GHz. The various frequency means a lot for the survey. Because it can give different spatial resolution and effect to survey depth achievement. The depth that GPR can achieve is depended on the antenna frequency (Słowik, 2011). The low frequency can survey deeper and obtain more data in vertical way but it gives quite unhewn resolution. On the other hand, the higher frequency antenna is suite for shallow survey. It reaches to a lower penetration depth but gives high spatial resolution. From this reason, it could not be tell that which exactly antenna frequency suit for survey. To choose correct antenna, it depended on site and research objective. For fluvial and meander research on a sandy site, mostly previous works use 100 and 200 MHz. e.g. Vandenberghe and Overmeeren (1999), Bano et al. (2000), Sambrook Smith et al. (2006), Kostic and Aigner (2007), Labey et al. (2009), Słowik (2011), Okazaki et al. (2015), Słowik (2016) The maximum penetration shows the best image of 100 MHz is approximately 16 meters and 200 MHz is approximately 6 meters (Bano et al., 2000; Vandenberghe and Overmeeren, 1999).

Matter composition is also exceptionally important for GPR accuracy of information. Different composition such as grain-size and moisture lead to dissimilar images even if they use the same antenna frequency. The change of dielectric constant can effect to energy which passing to the ground and can cause attenuation (Jol and Smith, 1992). The matters which have high dielectric constant (ε) and high electric conductivity (σ) but low resistivity like clay and groundwater can reduce penetration depth and also cause some signal loss or a stronger attenuation (Schrott et al., 2013). Moreover, the subsurface lithological boundaries can be visualized by strong reflection that result from the contrasts in the dielectric constant cause of different sediment types (Jol and Smith, 1991). Matter which present in vertical facie can be detect by discontinue in receiving signal. In case, matters like gyttja and peat, it is hardly to identify the discontinue layers in the deposition environment because they have quite the same of dielectric constant Also, both gyttja and peat is electrically conductive sediments. They are the clay-rich matter. The reflection signal cannot generate the differences (Słowik, 2011). Hence, GPR is limited working for survey in matter like mud and clay.

The last stage to prove the data from the GPR survey is an interpretation process. This process concentrates to the deciphering of interference patterns more than distinct reflections and diffractions that are characteristic of reflection seismic profile (Gawthorpe et al., 1993). The interpretation not only need the images that pass the process for enhancement and reducing noise but also need correlate data. Mostly, the correlate data which use to calibrate and ensure the result of reflection interpretation are profile, coring, borehole logs, outcrop, test pitting, geomorphic data and site observation (Ekes and Hickin, 2001; Schrott et al., 2013; Słowik, 2016). Furthermore, it requires the experience of an interpreter to get the reliable result.

In term of fluvial and alluvial fan environments study, the using of GPR can help to derive characterizing environment by reflection patterns and radar facies (Bristow and Jol, 2003). The numerous researches use GPR in order to derive the data for fluvial subsurface investigation. GPR aids in determining the sediment stratigraphic architecture, sand-body geometry and correlation and qualification of sediment structure. The diversity style of fluvial system, the heterolithic character of fluvial sediments, their depositional landform e.g. point bar, combined with fresh water make river deposits particularly suitable for survey by GPR (Bristow and Jol, 2003). Previous work like Ekes and Hickin (2001), they used GPR for study internal structure and facies of paraglacial allvial fan. Ekes and Friele (2003) used GPR to describe and interpret allvial fan deposit. They suggest that GPR can use to evaluate evolution of deposition in fan sequence. Also, it can use to assess in return period of debris flow and flood while formative was processed. Also, Roberts et al. (2003), they recommended that GPR is useful to study evolution deposit especially in preserve setting. They used GPR to illustrate facie of Holocene fan-delta deposit and indicate that delta sequence present a macrotidal setting. Furthermore, GPR is famous for study sediment in term of reconstruct the past environment. Słowik (2011), he used GPR to studied about reconstructing migration phase of meandering channel. Słowik (2016), he studied the influence of bend evolution on the formation of the cutoffs by using GPR to acquire profile of palaeo-bend. Besides, GPR can use to estimate depth of sediment deposition. Skelly et al. (2003), they studied about sandy braided river and use GPR to collect channel-belt deposition depth. Horn et al. (2012), they used GPR to prove the environment of platte river allvial facies model. They suggests that GPR can use to acquire depth of channels in subsurface alluvial valley fill and state reflection patterns of GPR (radar facies) to 7 patterns which are hummocky/wavy, high-angle clinoform, parallel, low angle clinoform curved, sigmodial and parabolic. It is a simply signal pattern for GPR fluvial survey and can interpret to characterize sedimentary structure

Chapter 3

Methodology

3.1 Study area

Mun River or Moon River is one of tributary of Mekong River. It originates from Sankamphaeng Range where is in Khao Yai National Park, Nakonrachasima. Mun River basin cover the area between latitudes 14° – 16° and longitudes 101°30 – 105°30 (Toda et al., 2004). Lengths through the Mun River is about 673 Kilometers and watershed is about 71,000 square kilometers. It flows through the south part of north-east Thailand and joint Mekong River at Khong Chian, Ubonratchathami (Akter and Babel, 2012). The area that Mun River flow through is called Khorat Plateau. It forms by tectonic uplift and mostly dominated by Mahasarakham, Phu Phan and Khok Kruat Formation. Those three formation are usually sandstones so, they make the river markedly see the effect of bank erosion and deposition. Khorat Plateau predominant landforms is undulating plain and low hills. Hence, the slope is not steep. Only Phu Phan Range is raised above 100 meters, general relief is about 20-30 meters. Characteristic of geomorphic of this area is defined by hugely deposition of Mekong River's alluvial (Dheeradilok et al., 1983; Loffler et al., 1984). Sediment from this deposition are taken place in several phase and can divine by erosion's period. Present landscape sedimentation can categorize to 4 main levels; the high, middle, low terraces and present flood plain.

Study area is a part of Mun River in western Buriram. (Figure9) It is an extensive and low gradient floodplain. This area is cover from latitudes 15°25'18.20"N - 15°25'8.48"N and longitudes 103° 8'26.13"E - 103°14'42.86"E. It is about 12 square kilometers in the western part of Buriram. According to RTSD GPS Ground Control Point no. 3531, area's elevation is 106.234 meters above mean sea level and slope is 8% (about 5 degrees). According to geology of Southern Khorat Plateau categorized by Loffler et al. 1984, this area is in lower Mun River basin. Basin is formed by sediment deposited in Quaternary that is cover above Mahasarakham Formation (5 – 155 meters). This formation is one of an outstanding characteristic of Khorat Plateau and

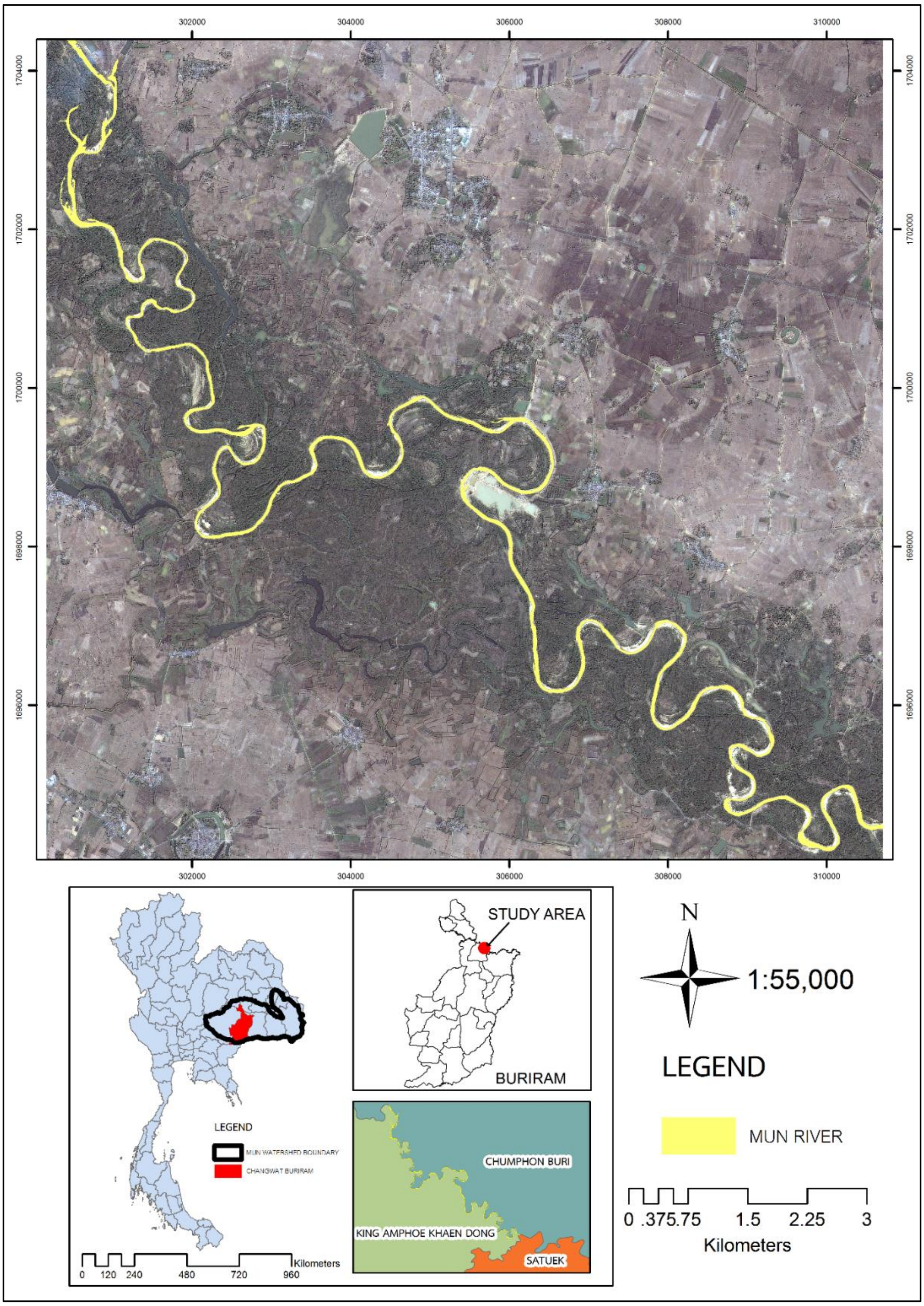


Figure 9 Map of the study area. Mun River is in western part of Changwat Buriram, Thailand. (A background image derived from ortho-image in 2009)

called salt formation.Because Mahasarakham Formation contained of shales, sandstones and salt. At 130 meters, also found Phu Phan Formation. This formation is presented by sandstones which is also found out croup and cuestas exposures along plain of Southern Khorat Plateau. Furthermore, Phu Phan Formation produces a series of rapids in the Mun River at the junction of Mekong River. (Figure10) Due to it is a countryside area, the river is surround by paddy fields and woods. There is not much construction that can effect to the river flow e.g. urban, dam, water gate and dike. The human construction where is close to the area is a weir about 10.4 kilometers above the stream called ‘Ban-Kae-Wa’. It was built in 1990and has run off around 1487 million cubic meters per year. So, the river can move freely and it make this area has a potential to exposure the nature of meander characteristic.

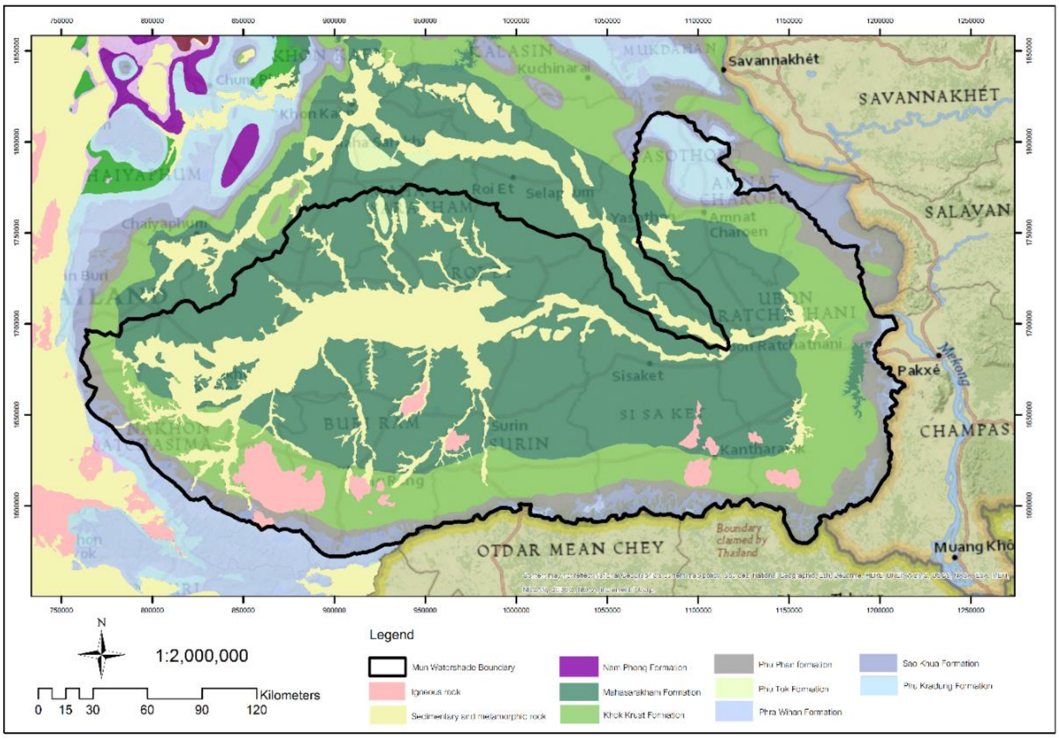


Figure 10 Geologic map of Mun River, Northeastern of Thailand. Mun River overlays on sedimentary rock (Yellow area) and is superimposing on Mahasarakham Formation (Dark green area). The geological data references by using Geological Map of Thailand, Geological Survey Division, Department of Mineral Resources, Thailand 1999.

3.2 Method

3.2.1 Aerial Photo and Satellite Image Interpretation

Using a series of aerial photo and satellite image that covering an area as show in Table 1 for interpretation. All the photos and images were cover in 33 years from 1976, 2006 and 2009. In 1976, using the aerial photo from the Department of Royal Thai Survey in map scale 1:50,000. Series of aerial photo were in greyscale and scanned to process as digital files. The geomorphic correction performed by using software from ESRI ArcGIS 10.2. Each photo was rectify by using 30 ground control points (GCPs) from Google Earth in UTM WGS1984 zone 48N coordinated system. The standard of Root Mean Square Error (RMSE) for photo rectification in this research has value less or equal to 10 m. In 2006, using satellite image form Quick Bird in resolution 0.5 m. In 2009, using both ortho-image in map scale 1:4,000 by Department of Lands and satellite image from Landsat 5 in resolution 30 m for geomorphic interpretation. The reason for using both ortho-image and satellite image is to ensure the shape of meander scars and other geomorphology. Because ortho-image has some noise. The aim of interpretation is focusing on channel geometry and modern landforms. Geomorphology was identified by using different colours, sizes and shapes and created as shape files for comparison and measurement parameter for geomorphic criteria calculation. The modern channel of each year was digitized and delineated by using riparian of bank and vegetation.

Table 2 Aerial photos and satellite images source

Year	Date Achieve	Data Type	Resolution	Source
1976	17th November	Aerial Photo	1:50,000	Royal Thai Survey Department
2006	21st January	Satellite Image	0.5 m	Quick Bird
2009	24th December	Ortho Image	1:4,000	Department of Lands
2009	25th March	Satellite Image	30 m	Landsat 5

3.2.2 Geomorphic Criteria Calculation

There are 3 geomorphic criteria, which are channel width (W), sinuosity index (SI) and radius of curvature (RC), use for estimate change of meander in this study. All of these have their own formula and details which are benefit for measure geometry change in different periods.

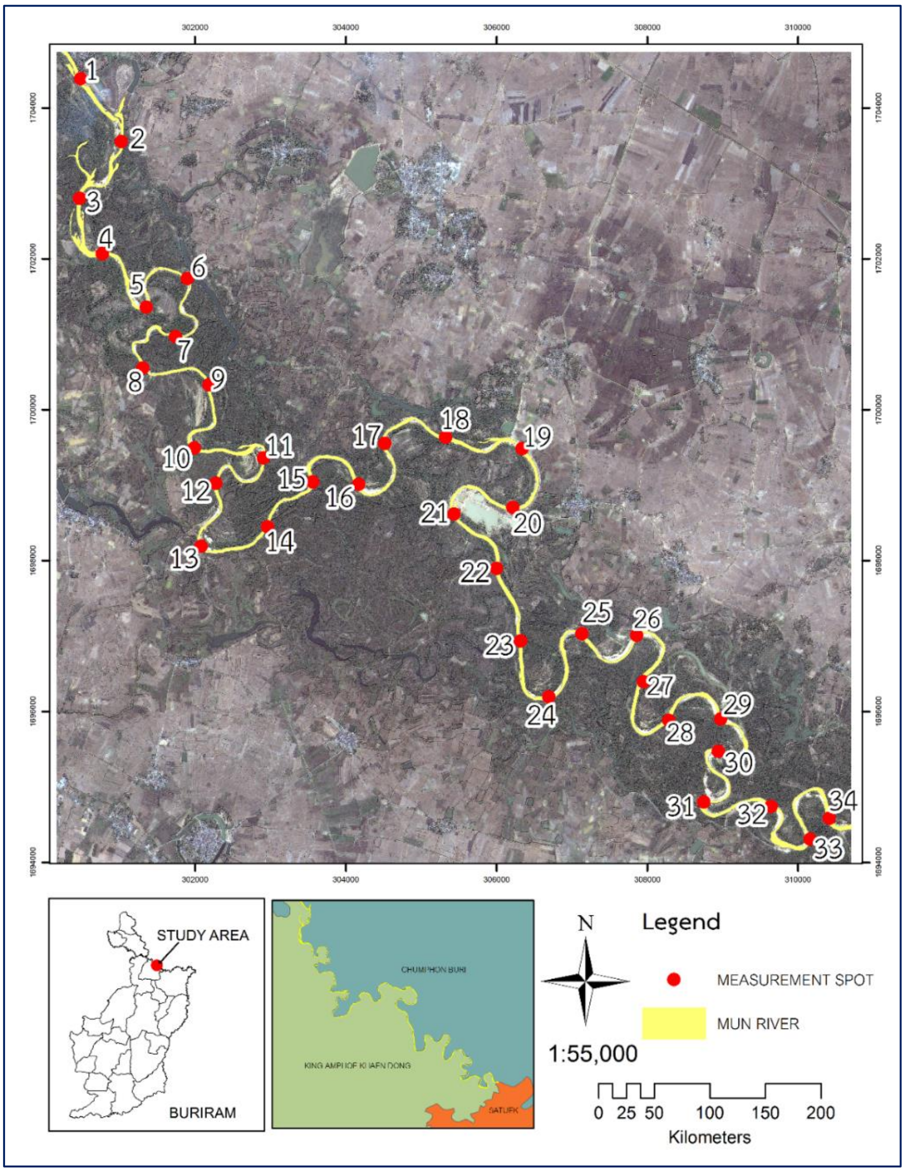


Figure 11 Map of study area of Mun River in western part of Changwat Buriram, Thailand with the measure spots and their spot number. The spots were ploted along the modern channel every 1 km. (A background image derived from ortho-image in 2009)

Channel width (W) is a distance between two points across the bank. The change of channel width can be affected by water level and longitudinal slope (Duró et al., 2016). Water level is quite dynamic and temporary; it cannot be affected much and long to channel width markedly as a longitudinal slope. To change a longitudinal slope, it is an effect from deposition and erosion. Therefore, channel width can be a good representative for measuring the channel change during different periods. Not only to measuring how much channel change but it can also be used to monitor the trend of channel which is erosion or deposition mostly takes place. In this study, it is managed to measure the channel in every 1 km along the Mun River (Figure11). Hence, a result is interpreted from 34 spots.

Sinuosity index (SI) is used as a geomorphologic criteria to depict change and measure channel stability. SI coefficient is 1.05 but not more than 1.25, a river is sinuous. 1.25 until 2, it shows that it is a meandering river. Up to 2, it is a highly meandering. Hooke (2007) suggests that river channel can adjust themselves when SI is about 2 which is a highly meander. Hence, this study is including the index to see the trend of SI value to match with channel shape and tries to predict the change of Mun River. The distance of down valley and channel length were applied to aerial photo and satellite image as figure12, 13 and 14. Both values measured by using Measure Tool from ArcMap 10.2. For paleo-belt, it was measured by the same method at the spot which has a full loop as show in figure5.

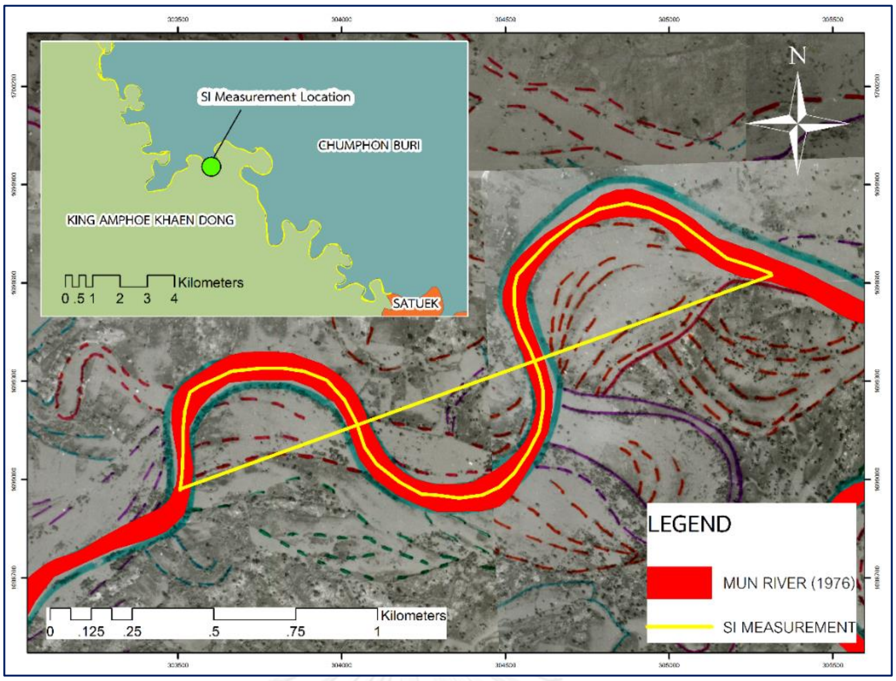


Figure 12 SI of 1976. SI theory from Brice (1964) was applied to channel bends and measured for channel length and downvalley distance (Yellow line). Map scale is 1:10,000. The location of bends presented in an up-left small box. (A background is an aerial photos from 1976 by Royal Thai Survey Department 1:50,000)

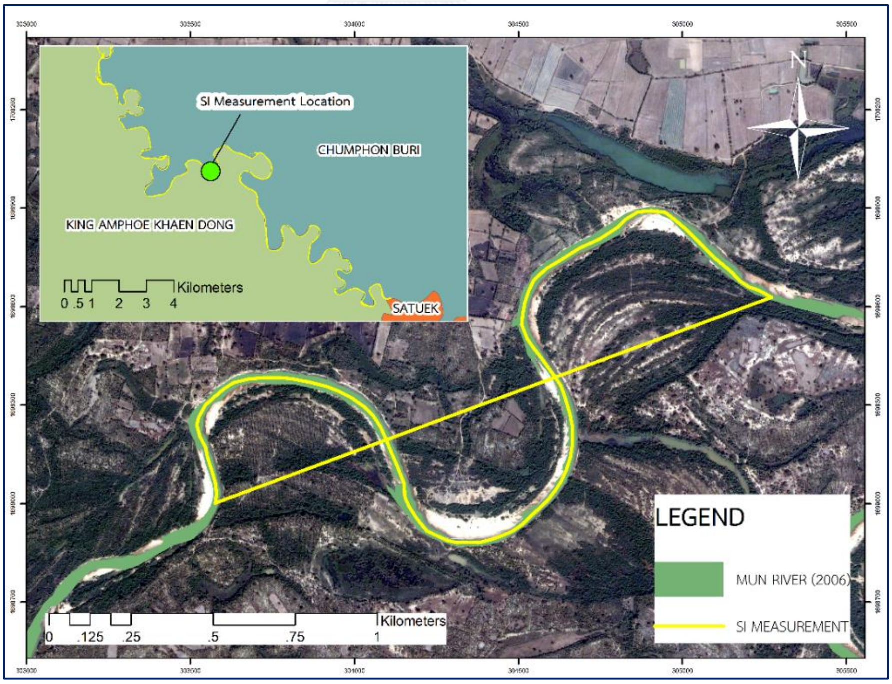


Figure 13 SI of 2006. SI theory from Brice (1964) was applied to channel bends and measured for channel length and downvalley distance (Yellow line). Map scale is 1:10,000. (A background is a satellite image from 2006 by Quick Bird resolution 0.5 m)

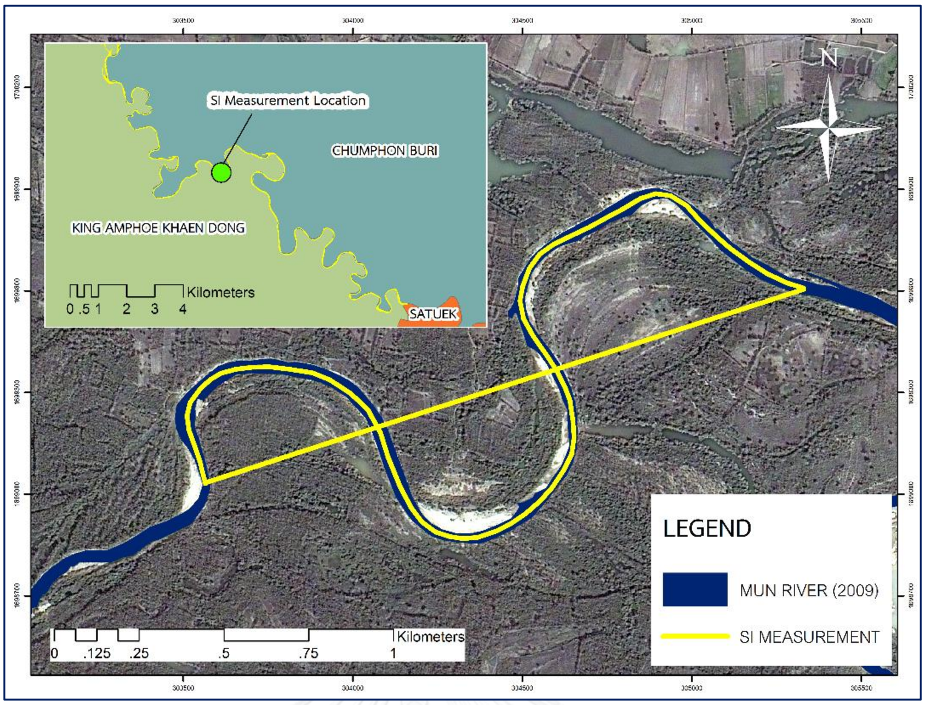


Figure 14 SI of 2009. SI theory from Brice (1964) was applied to channel bends and measured for channel length and downvalley distance (Yellow line). Map scale is 1:10,000. (A background is an otho-image from 2009 by Department of Lands 1:4,000)

The last geomorphologic criteria is radius of curvature (RC). This criteria is using for evaluate channel stability. RC estimates from the outside of the bank-full channel to the intersection point (figure15). The value from this criteria is considered as an average RC because it means to the center of the curve. In this study, RC was calculated from the same curve in 1976, 2006 and 2009. The spot which give RC will be a representative spot of the river each year for result comparison.

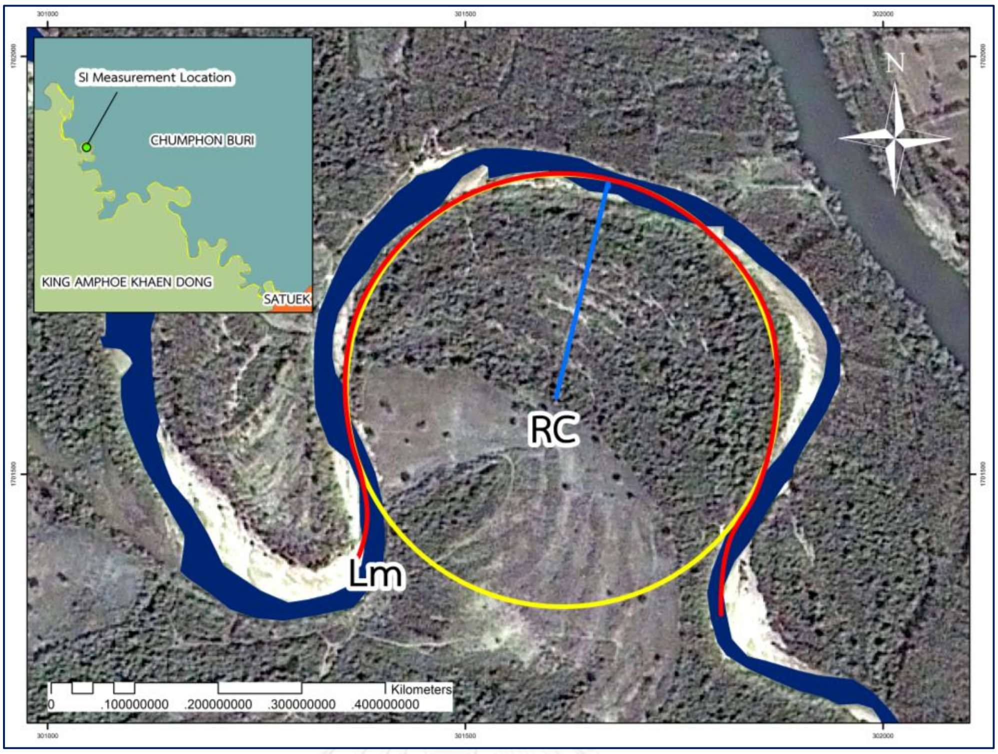


Figure 15 RC of Mun River. Lm was measured from the distance between 2 apexs of the bend. RC which is calculating form this method consider as an Average RC. RC value means to the center point of the bend. (A background image derived from ortho-image in 2009)

3.2.3 GPR Survey

Total 8 GPR profiles were collected form 2 study sites on point bar in both side of Mun River. (Figure16) The survey used The Geophysical Survey System Inc, USA (GSSI) with SIR-20 GPR system and a center frequency monostatic shielded 200 MHz antenna. The antenna can acquire approximately 6 meters (Bano et al., 2000; Vandenberghe and Overmeeren, 1999) from subaerially in sandy site. During the survey process, an antenna was attached with an odometer based survey wheel for distance tracking and was continuously dragged along a survey line. Every survey lines were collect the position on start point and finish point by eTrex10 Garmin GPS.

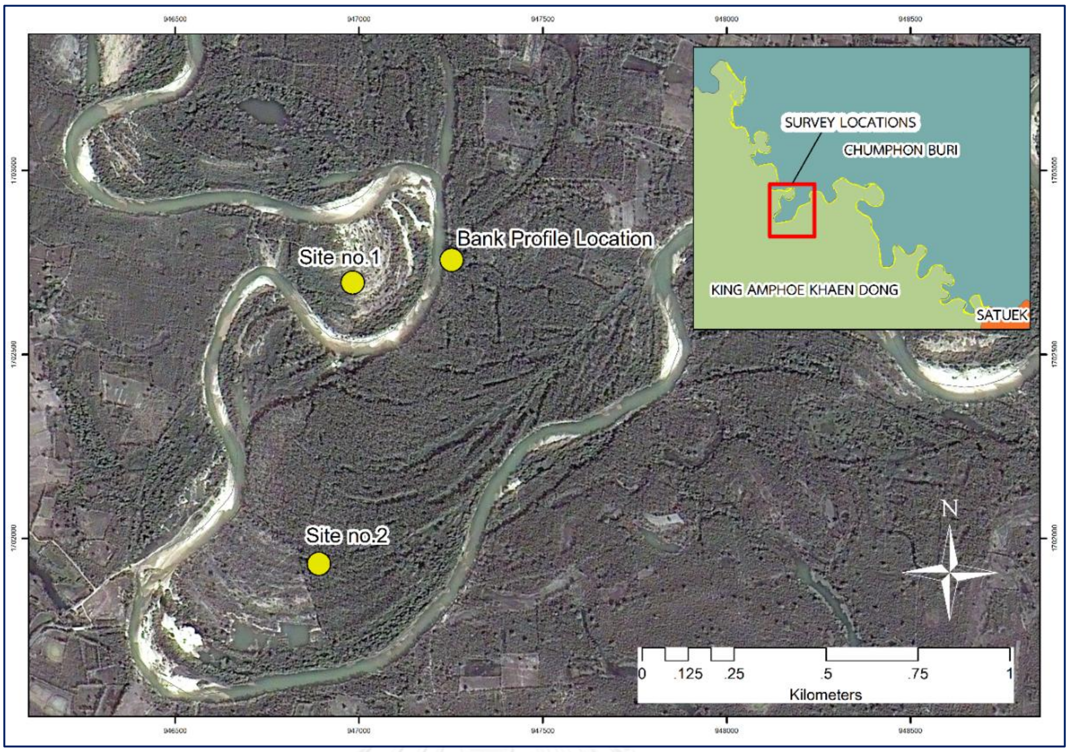


Figure 16 GPR and bank survey location in study area, Mun River western part of Changwat Buriram, Thailand. GPR survey site located on point bars in both side of Mun River. Meanwhile, bank profile collected from the river bank which located in the opposite bank of site no.1. (A background image derived from ortho-image in 2009)

At site no. 1, GPR was designed to survey across the floodplain. (Figure17) Line 1 and 2 were survey in transverse way of the swales. Line 3 and 4 survey along swales (lateral side). Swales which in this site is a modern swale. The reason for this survey design is showing both flow-parallel and flow-transverse GPR profile. The long of lines survey are 180 m, 180 m, 175 m and 195 m, respectively. The reason of variable length is there are obstacles like woods and trees which are blocked the survey line. The signal from GPR line 1 – 4 can interpret structure of subsurface structure. Line 5 is a long profile which was surveyed on the road across the point bar. This profile represents cross swale structure with topography adjust. Moreover, there is a bank profile that was collected from the bank across site 1 as point show in figure16.

Site no. 2 is a biggest point bar in the study area. It was designed to survey in 3 lines as show on figure18 Line 6 and 7 is an ancient point bar survey. Line 8 is a modern point bar survey with stratigraphy logging. During survey process, line 6 and 7 designed to survey cross each other to see the point bar in 3D structure. Line 6 and 7 are 60 m and 45 m long, respectively. Next survey is line no.8 survey. The survey is total 120 m long but it has to separate to 2 section which is 8a and 8b because of an obstacle. Section 8a is 70 m long survey with 2 stratigraphy profile and 8b is 50 m long with 1 stratigraphy profile (Figure19)

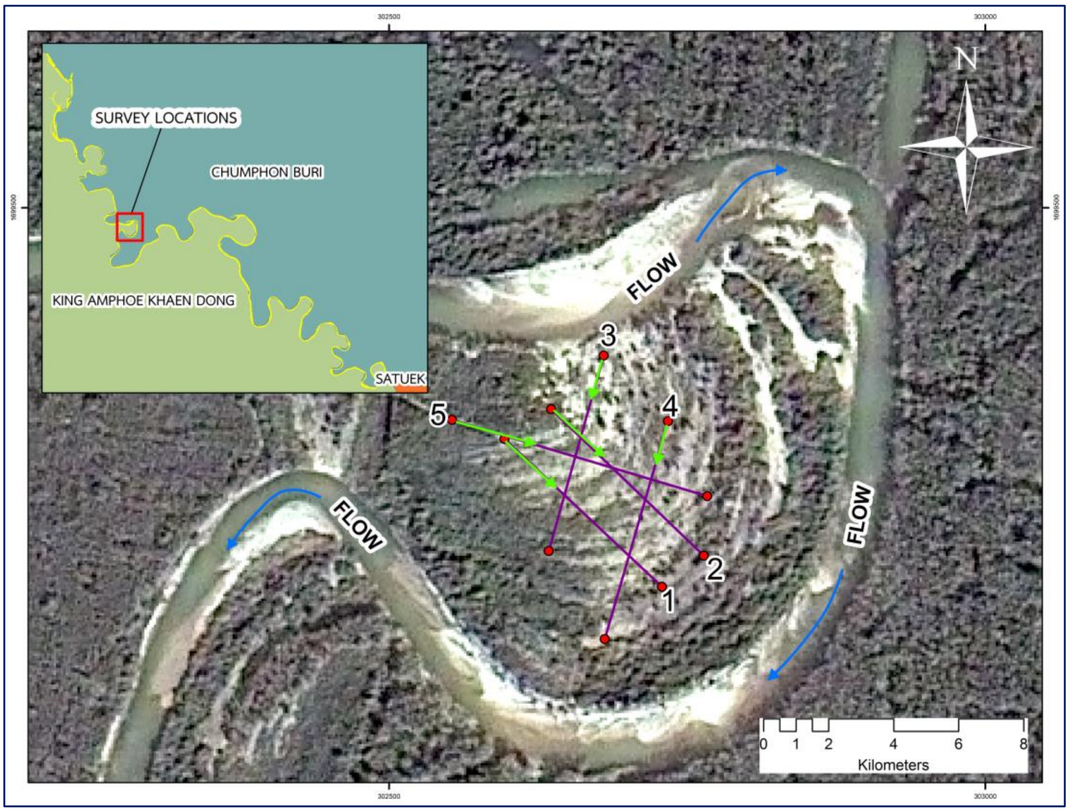


Figure 17 GPR Direction on study site number 1, Mun River western part of Changwat Buriram. 5 GPR lines achieved on a sandy point bar site by using 200 MHz. The direction of GPR survey showed by arrow. (A background image derived from ortho-image in 2009)

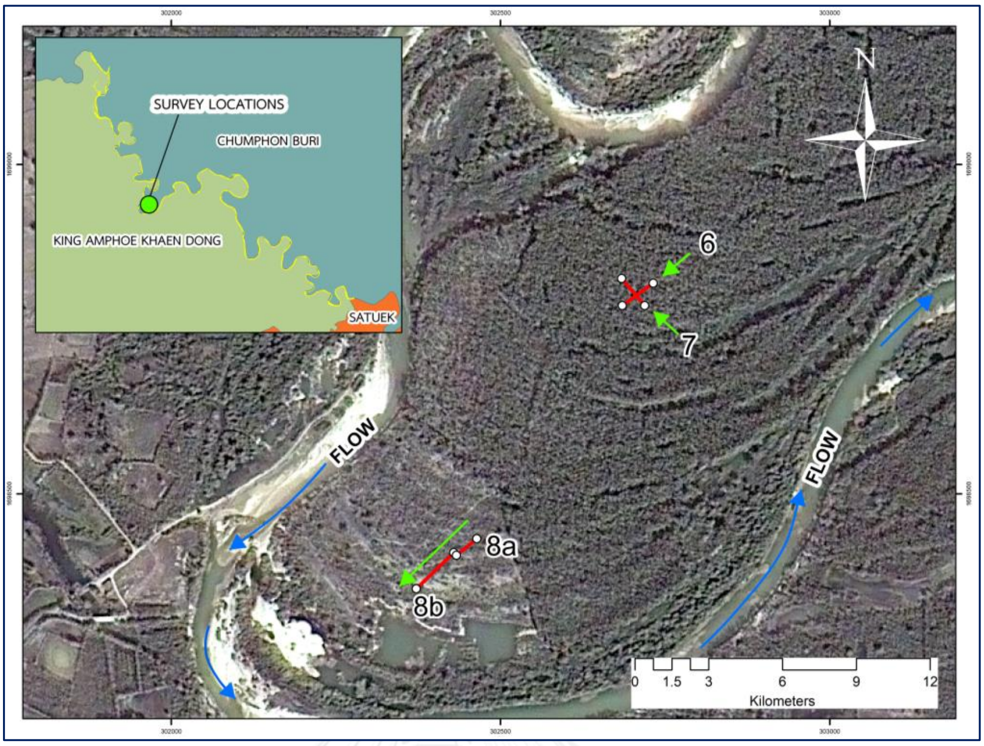


Figure 18 GPR Direction on study site number 2, Mun River western part of Changwat Buriram. 5 GPR lines achieved on a sandy point bar site by using 200 MHz. The direction of GPR survey showed by arrow. (A background image derived from ortho-image in 2009)

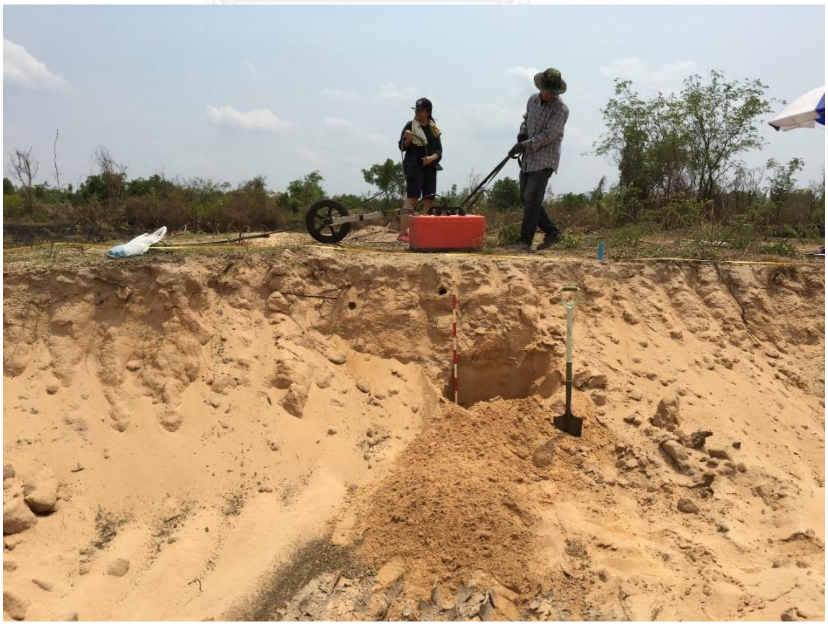


Figure 19 Survey line 8 from site no.2 of Mun River western part of Changwat Buriram. The site no.2 located on a point bar. This survey lite processes on the road cut profile by using GPR with 200 MHz antenna and documented a profile along with the survey.

3.2.4 GPR Signal Interpretation

After the survey, all GPR signal was process and interpretation. This study uses Radan66 as a software for process signal to an image. Before process, GPR is a signal from 2 travel times of wave in n/s. Radan66 processes to depth along the distance that was collected by survey wheel. The raw images has removing high frequency noise and enhance for better quality. The interpretation basically based on an unconformity of signal line on the image. The result lines from the unconformity interpretation were combine with environment data which is bank profile and stratigraphy before make a summary of subsurface structure. Also, this study uses interpretation guideline from previous work on a sandy fluvial site like Vandenberghe and Overmeeren (1999), Skelly et al. (2003), Shukla et al. (2008) and Horn et al. (2012) to help to identify the meaning of GPR signal.

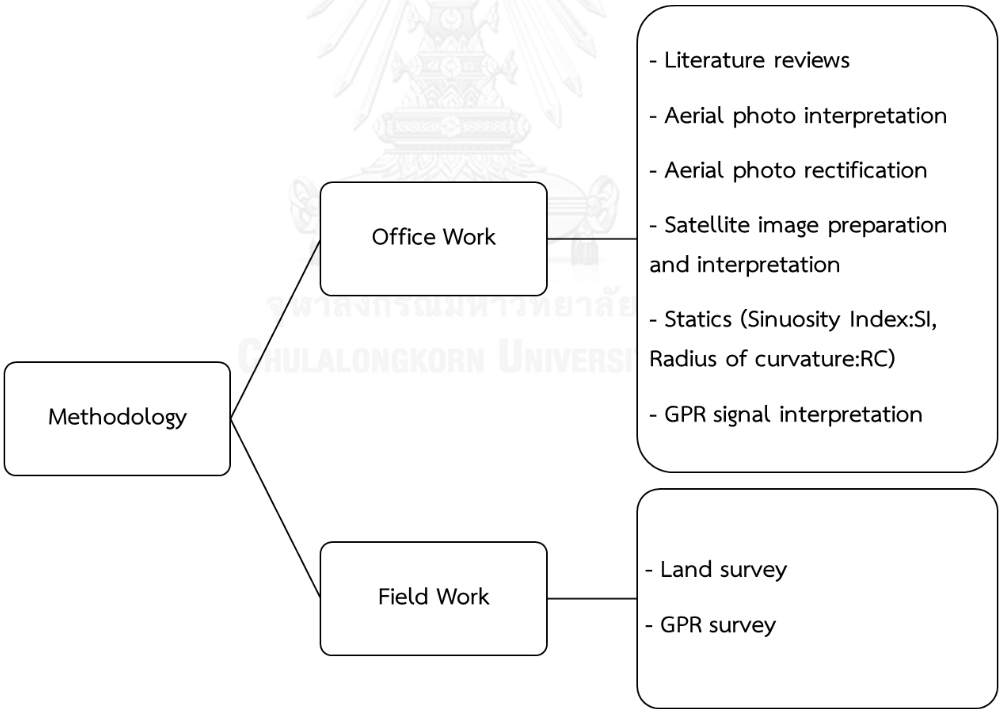


Figure 20 Synopsis Flow Chart of Working Process for study Fluvial Geomoorphology Change during 30 years of Mun River Western Part of Changwat Buriram, Thailand.

Chapter 4

Results

4.1 Sinuosity Index (SI)

It found that Mun River in the study area has measured SI in 1976, 2006 and 2009 are 1.5, 1.8 and 1.8 respectively. According to SI index theory, it categorizes to be meandering class which has a highly sinuosity. Aerial photos and satellite images show obviously trace form movement of river across the floodplain. Comparing between 1976 and 2006, the Mun River during this 30 years is increased sinuous from 1.5 to 1.8. Then, it can assume that in this period erosion and deposition rate is increasing too. On the other hand, Mun River in 2006 and 2009 have the same SI which is 1.8. It can imply that during 2006 and 2009 channel is stability. The rate of erosion and deposition remained steady, so the channel can maintain their shape and not to be more sinuous. Furthermore, traces in this area exhibited that Mun River had hugely rate of erosion and deposition and also formed lots of geomorphology such as point bar, cutoff and oxbow lake. It can infer that the Mun River in study area is in a mature age and the terrace is not adjust to the lower elevation yet.

Table 3 Summary of SI index from 1976, 2006, 2009

Year	SI Index
1976	1.5
2006	1.8
2009	1.8

4.2 Radius of Curvature (RC)

According to figure21, RC had measurement from 5 different bends cover all a study area. Bend number 1 and 2 has risen RC but bend number 3 – 5 RC has fallen in 2006 – 2009. (Figure22) The migration rate of study is 0.5 – 1.8 meter per year.

Focusing on relationship between RC and channel width, both of parameters can use to show bend curvature which is used to normalize with migration rate for evaluate meander geometry. When plot a normalizing graph between migration rates and bend curvature, the value which falls to 1 -2 means that bend will cut off either chute cut off or neck cut off. If value falls between 2.5 to 4, bend will have high erosion rate. If value rises more than 5, bend will have low erosion rate (Nanson and Hickin, 1983). As shown on graph (Figure23), in 1976 bend number 2 has high erosion rate and bend number 5 may have cut off. In 2006, bend number 5 has high erosion rate. The others spot form 1976, 2006 and 2009 have value that fall more than 5 which mean low erosion rate. From data in graph figure20, it can infer that Mun River in the study area has decreasing erosion rate during 30 years period.

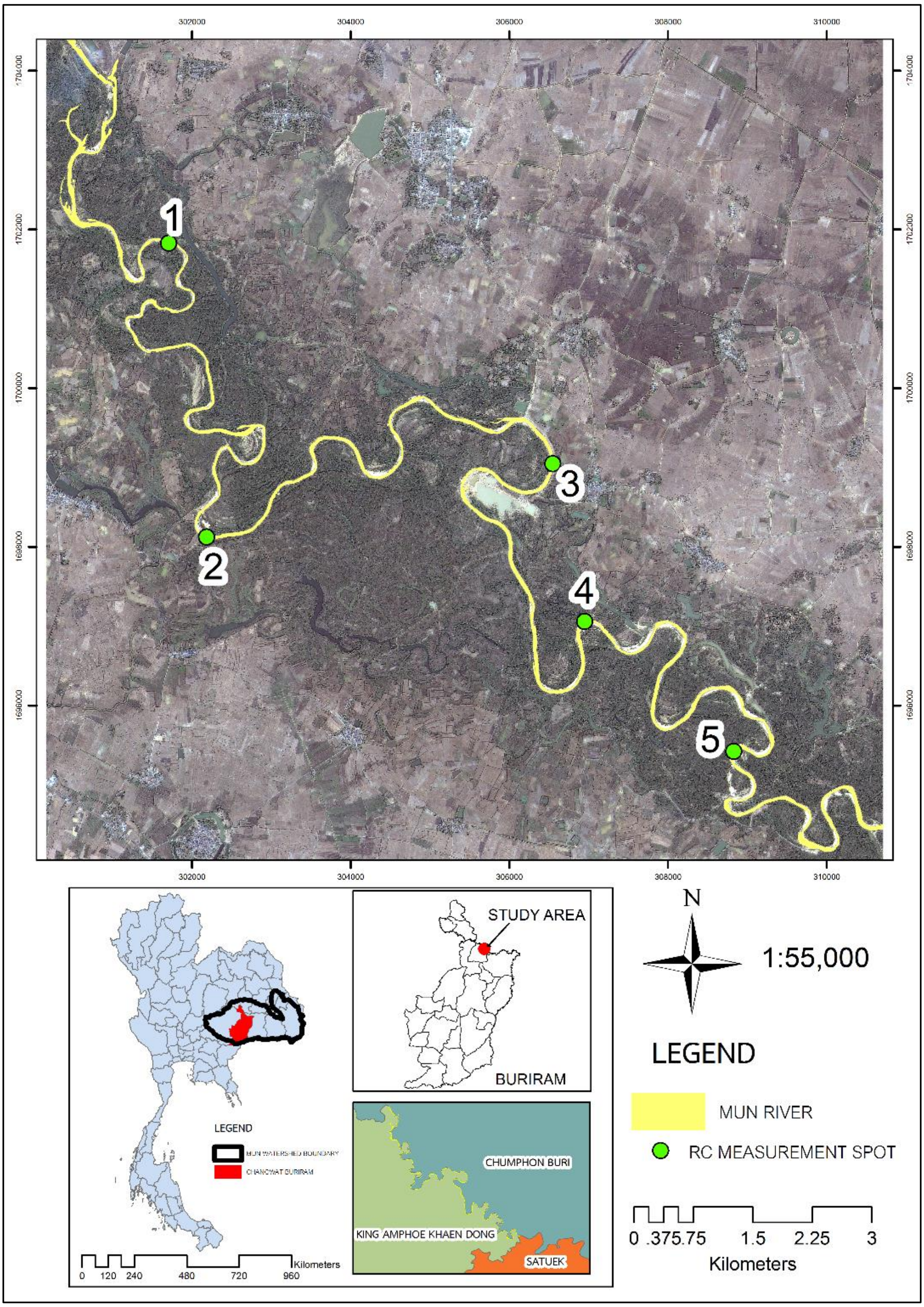


Figure 21 RC Measurement Locations along Mun River western part of Changwat Buriram, Thailand. (A background derived from an ortho-image, 2009)

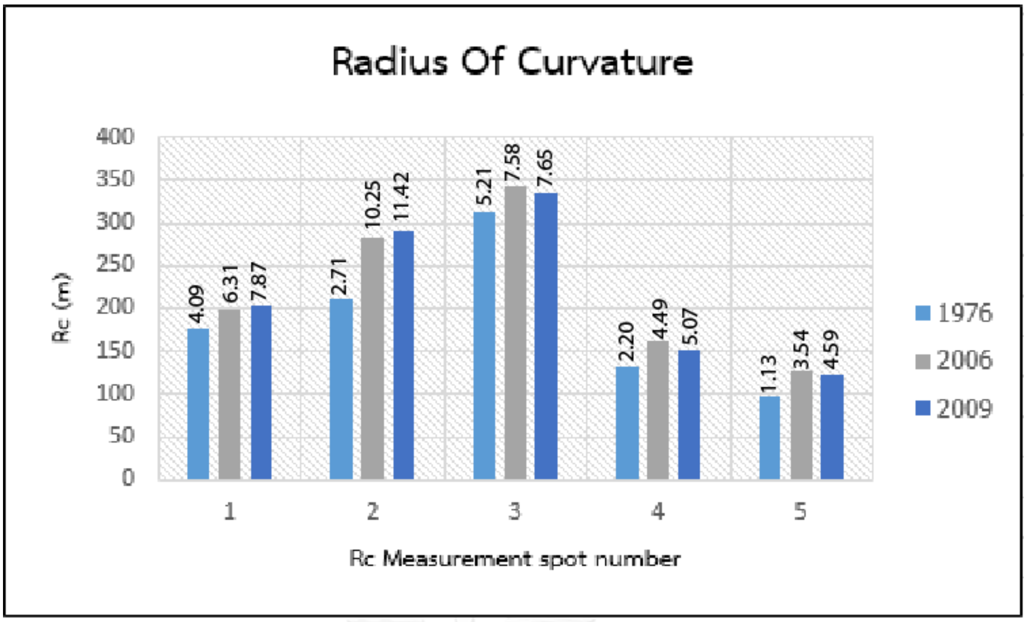


Figure 22 RC during 1976-2009. The RC value considered as an Average RC which is refer to the area at the center of a river bend. RC was measured and calculated form the 5 bends in different locations (figure21). The rise of RC value in every bends can assume that river bend in the study area developed to be a stable one compare in 33 years period (1976 – 2009).

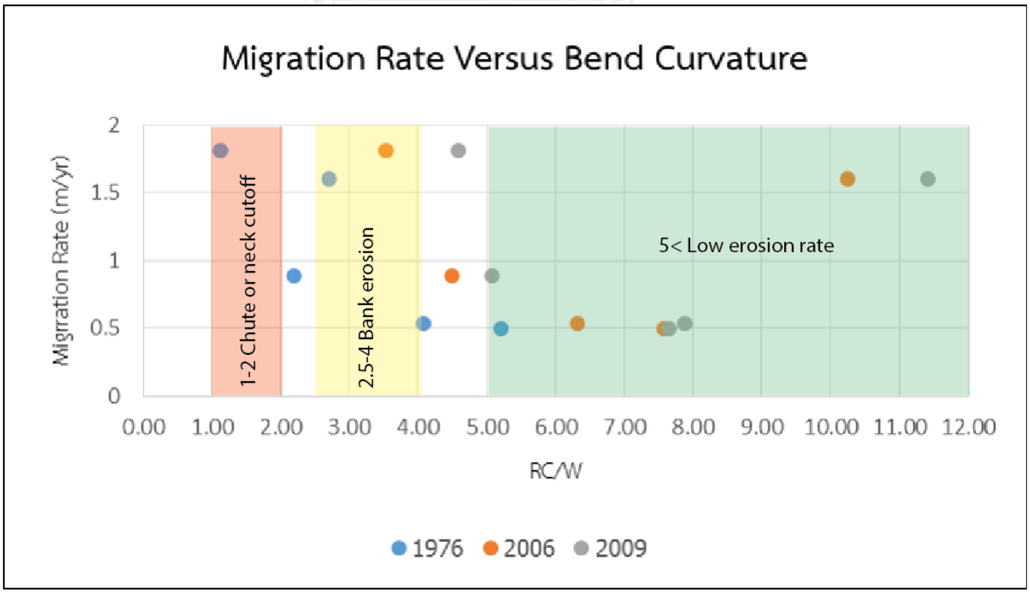


Figure 23 Meander Migration Rate versus Bend Curvature (RC/W). The normalize of RC and W can show the rate of migration form each bend. In this area found that 3 bends have high erosion which are point no. 1 and 2 from 1976 and point no.5 from 2006. Also, it found that point no.5 in 1976 tend to be a chute or neck cutoff.

4.3 Channel Width (W)

Due to the result from measuring 34 spots along the river (figure11), channel in 1976 is wider about 2 times comparing to 2006 and 2009. (Table4) An average channel width in 1976, 2006 and 2009 are 72.05 m, 33.34 m and 40.28 m respectively. At the same spot but different year, it has clearly different width value especially at the bend. (Figure24) For example spot number 5 and number 8, as show in the graph (figure25), there is hugely gap of channel width value and both spots are concave bend. In conclusion, the Mun River in 1976 is widest and 2009 is wider than 2006.

Table 4 Channel Width Measurement. The measuring spot is available every 1 km along Mun River in the study. The channel width values derived from aerial photos and satellite images.

Measuring Spot Number	1976 (m)	2006 (m)	2009 (m)
1	89.34	76.45	83.95
2	46.31	27.40	38.01
3	68.20	45.28	57.60
4	90.37	46.55	51.53
5	63.34	28.46	20.40
6	55.99	16.84	20.75
7	74.65	28.05	42.58
8	40.98	20.05	32.43
9	65.49	24.62	35.75
10	62.58	32.99	37.34
11	57.17	36.65	36.82
12	92.84	22.87	36.84

Table4 Continue

Measuring Spot Number	1976 (m)	2006 (m)	2009 (m)
13	75.29	20.73	18.56
14	66.75	34.09	44.78
15	75.38	20.45	23.13
16	79.40	44.91	42.20
17	71.22	30.96	28.86
14	71.47	14.42	39.28
15	54.72	36.11	38.67
16	75.64	34.44	41.82
17	49.85	21.36	47.31
18	90.73	55.54	50.65
19	83.17	47.56	47.18
20	85.79	34.16	39.73
21	76.47	24.85	22.11
22	91.85	47.61	56.20
23	89.34	76.45	83.95
24	46.31	27.40	38.01
25	68.20	45.28	57.60
26	90.37	46.55	51.53
27	63.75	21.69	29.50
28	78.37	44.39	49.54
29	89.92	16.99	35.13
30	65.54	31.09	49.86

Table4 Continue

Measuring Spot Number	**1976 (m)**	**2006 (m)**	**2009 (m)**
31	63.38	46.70	46.39
32	79.34	34.31	36.39
33	70.01	14.86	20.71
34	84.23	50.22	67.54
Average	72.05	33.34	40.28

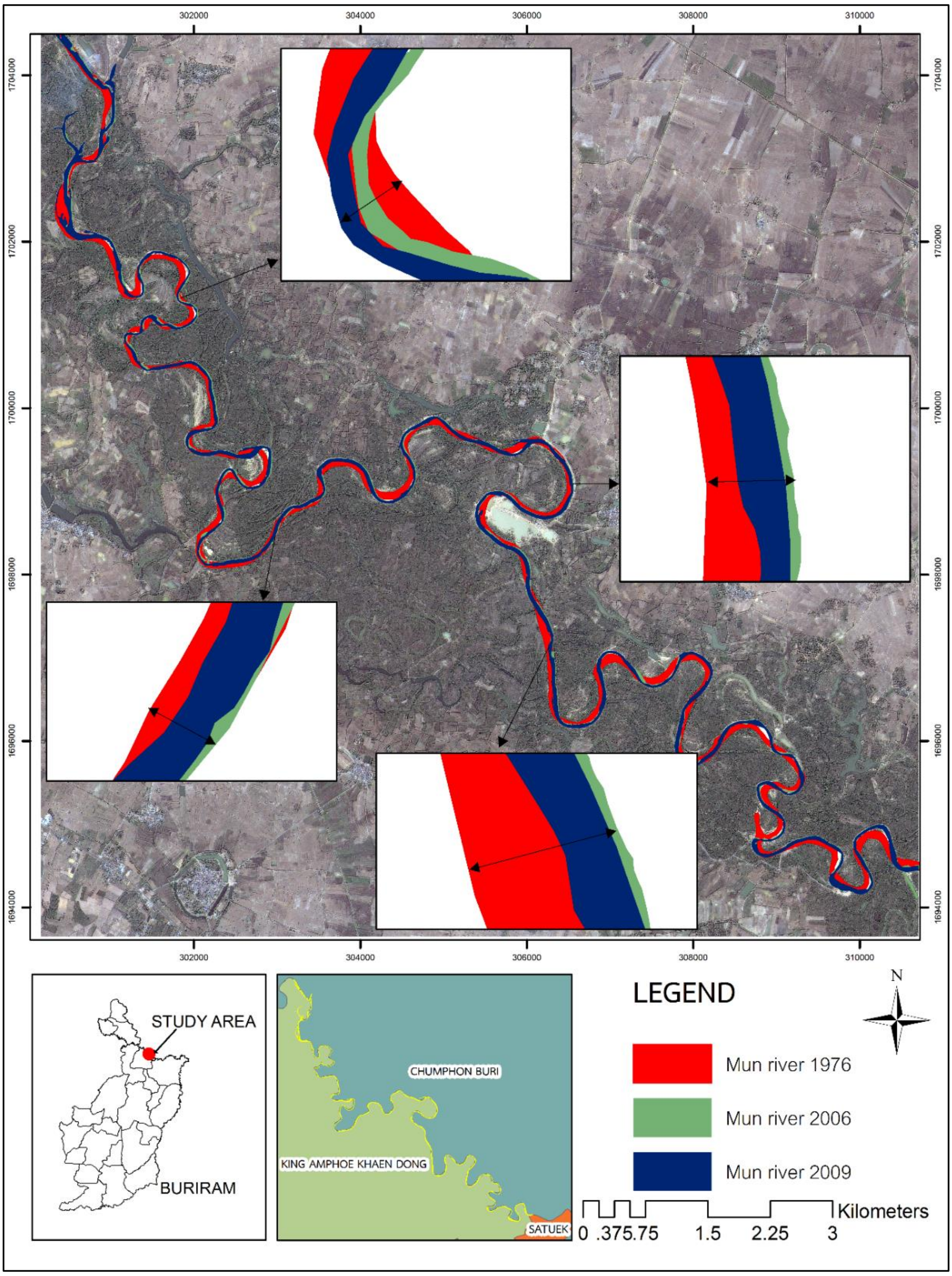


Figure 24 Comparison of Channel Width in 1976, 2006 and 2009 of Mun River western part of Changwat Buriram, Thailand. (A background derived from an ortho-image, 2009)

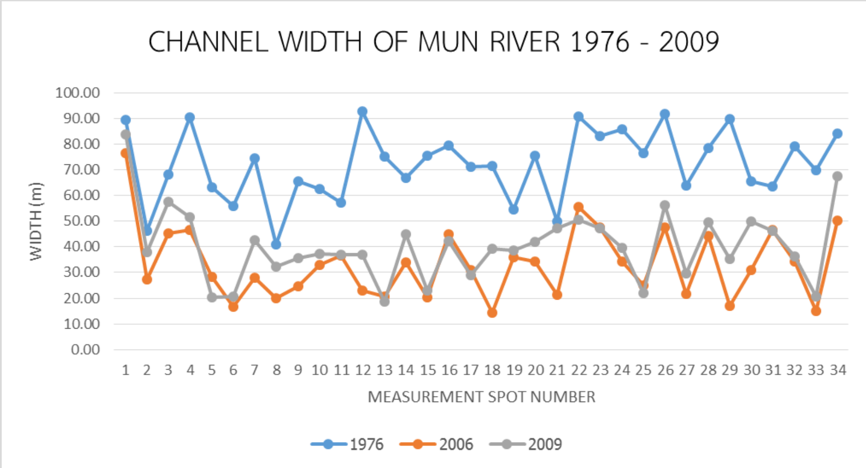


Figure 25 Channel Width Graph of Mun River western part of Changwat Buriram. The width was measured from 34 spots that located every 1 km along Mun River.

4.4 Modern Belt and Paleo-Belt

From aerial photos and satellite image interpretation, it found that landform of study area represent meander scars, oxbow lakes and point bars. Also, it found paleo-channel belt of Mun River is lied under the recently one. According to figure26, there is a lot of meander scars spread on the floodplain and some are existed out of floodplain boundaries. It can infer that before 1976 Mun River had adjust the terrace to the lower elevation and formed the modern floodplain. Meander scars under the modern Mun river was represent paleo-channel. It can infer that Mun River shifted up to north direction. However, meander scars from the upper modern Mun is also interesting. Even though it cannot connect as a long channel as meander scars which found in the south, it can represent the paleo-point bars. When trying to looking at meander scars shape, it might be the big paleo-point bar. Many villages was setting on this point bars and has urban plan along the curved up shape. It look like in the ancient time this the river was pass along their villages. Furthermore, this study was trying to combine loops from paleo-belt for calculating geomorphic criteria. Sinuosity index (SI) of the paleo belt is 1.9 which means the belt is in a highly sinuosity class. Rc/w is also calculated by using a sample site from figure29. The paleo-belt has rc/w various from 1.5-2.2 which make channel is rank in a high erosion rate.

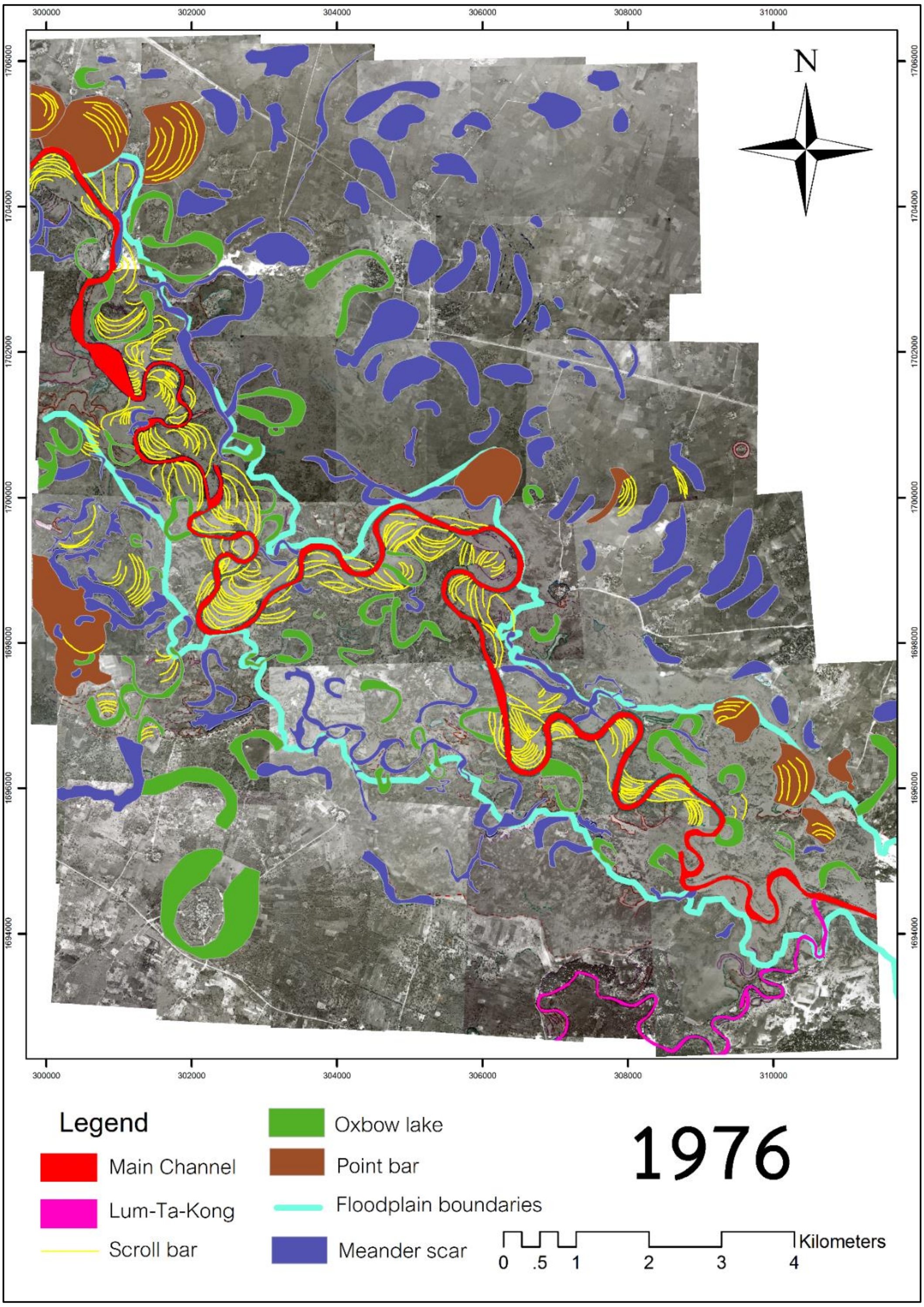


Figure 26 Geomorphic Identification Map, 1976 of Mun River western part of Changwat Burirum,Thailand. Interpretation done by using aerial photo 1:50,000. Floodplain boundaries references from Map L7018 (2006) by Royal Thai Survey Department.

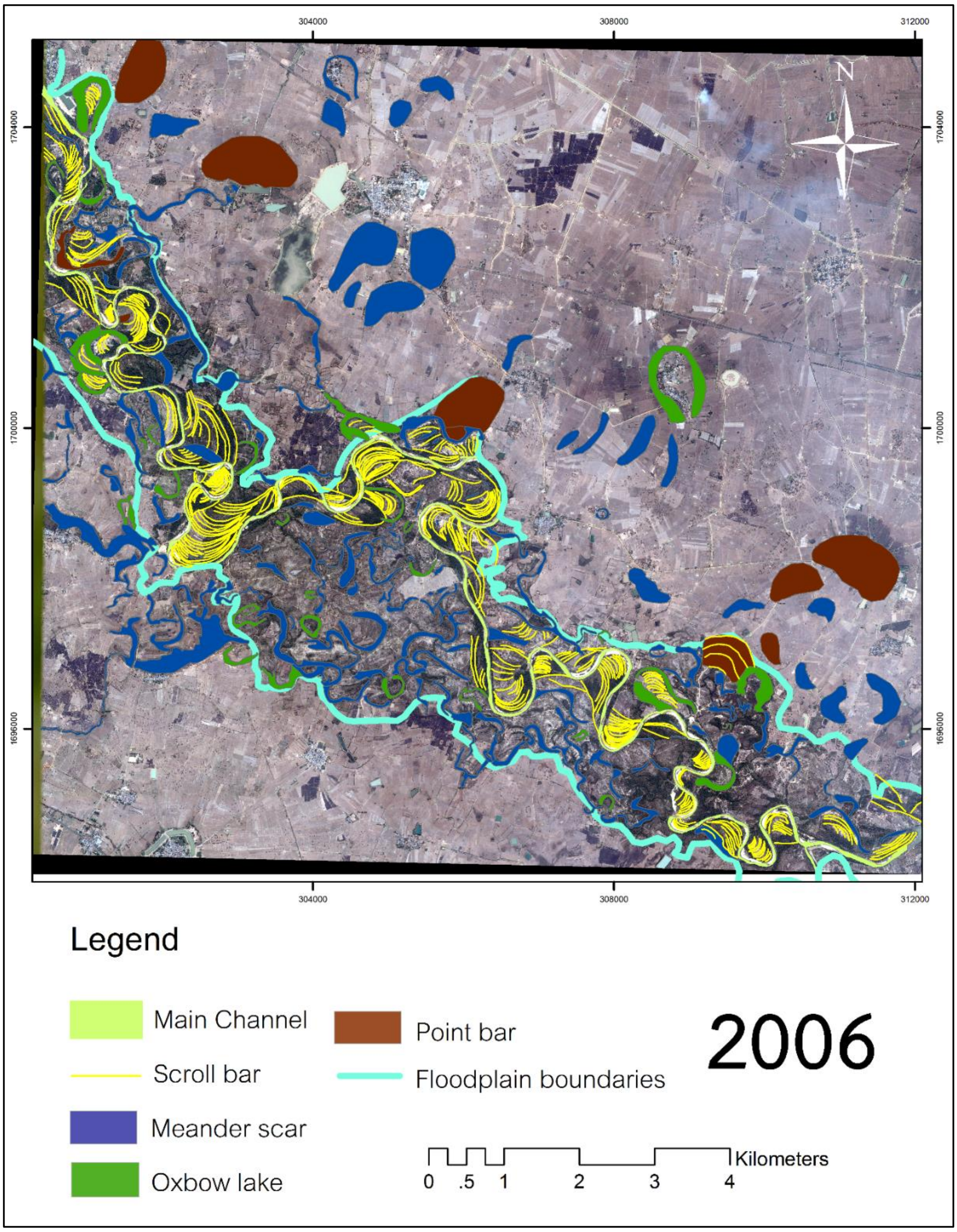


Figure 27 Geomorphic Identification Map, 2006 of Mun River western part of Changwat Burirum,Thailand. Interpretation done by using Quick Bird satellite images, 0.5 m resolution. Floodplain boundaries references from Map L7018 (2006) by Royal Thai Survey Department.

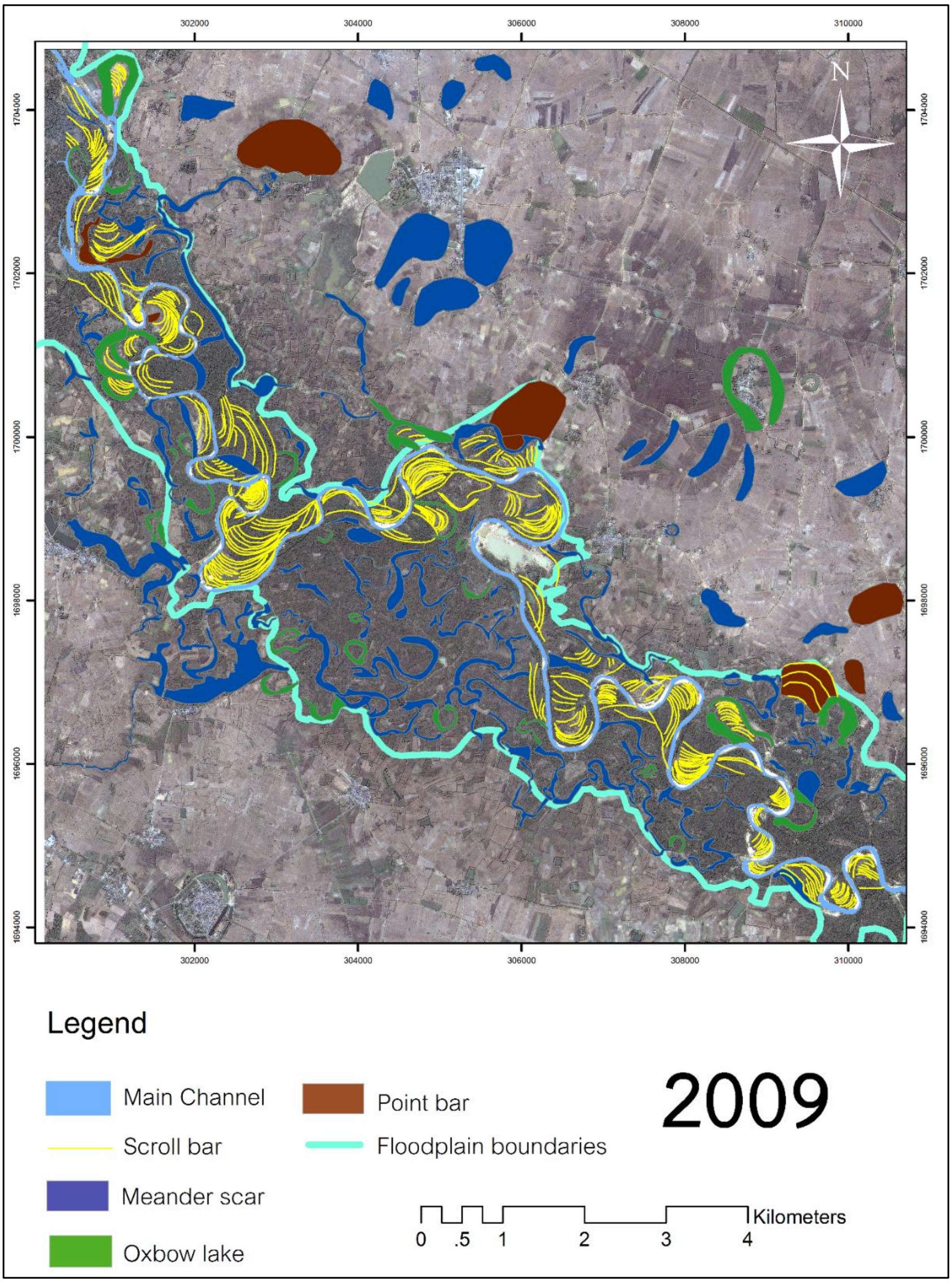


Figure 28 Geomorphic Identification Map, 2009 of Mun River western part of Changwat Burirum,Thailand. Interpretation done by using other-images 1:4,000. Floodplain boundaries references from Map L7018 (2006) by Royal Thai Survey Department.

Figure 29 Map showed paleo-channel belt under the modern Mun River. The modern channel showed in the map is digitized by using satellite images 2006 from Quick Bird resolution 0.5m. RC was calculated from 5 differences spot along the paleo-belt. The base map derived from ESRI World Street Map.

4.5 GPR facie and profile

4.5.1 GPR Facies

Using reference in the interpretation part form Vandenberghe and Overmeeren (1999) , Skelly et al. (2003), Lunt and Bridge (2004), Shukla et al. (2008) and Horn et al. (2012), 8 GPR radar facies were recognized in meander depositional environment

Facies 1.- Facies 1 presents hummocky or wavy line. Mostly, it lays in horizontal way. If facies 1 appears as a group of reflection, it refers to trough cross beds. In order to found facies 1 overlies the concave up or curved reflection, this can interpret as channel fills (Skelly et al., 2003). The direction of channel fills always toward curved or something have low angle dipping into curved shape. Furthermore, facies 1 can interpret as side bar deposit if it appears underneath curved shape (Lunt and Bridge, 2004). In short, facies 1 is interpreted as trough cross beds channel fills or side bar deposit which is different by their details.

Facies 2.- Facies 2 is typically found in this area. The pattern of reflection is almost a curved down or shingle. Facies 2 can represent various types but most of it is about migration. The most common to interpret facies 2 is lateral migration. It presents as a long reflection may up to 3 m both continues and discontinue but has the same direction. In general, facies 2 which is represent lateral migration has direction toward flow direction. Facies 2 can also interpret as slipface of migration bedform (Lunt and Bridge, 2004). The reflection lays in a condition like lateral migration but may again flow direction. Moreover, facies 2 can be refer to lateral accretion. The reflection character be short about 1 m or long than 3 m but nearby must found erosion surface or channel (Horn et al., 2012). The last meaning of facies 2 is downstream migration. It has a condition quite similar to lateral migration but found it gives longer continues GPR signal. The reflection can be long up to 10 m depending on a point bar size (Vandenberghe and Overmeeren, 1999). In summary, facies 2 represent to the characters of lateral migration, slipface of migration bedform, lateral accretion and downstream migration.

Facies 3.- Facies 3 found as sets of en-echelon or sigmoid. The shape of sigmoid is parallel but sometime incline but still in oblique shape. The reflection angel is about

15 – 45 degrees. It can be interpret as migrating of channel bar. According to Lunt and Bridge (2004), facies 3 is possible to be unit bars as it combines sigmoid and can separate to sets. Facies3 is an outstanding reflection character of modern floodplain.

Facies 4.- Facies 4 considers as erosion surface or channel which represents by curved and concaved up. (Skelly, 2003) Curved shape may be symmetric or asymmetric (Vandenberghe and Overmeeren, 1999). The width of curved is vary from 3 but not more than 10 m.

Facies 5.- This facies contain of concave up shape which is isolated, may symmetric or asymmetric trough-like. The highs of facies5 are about 0.5 – 1 m and 2 – 4 m long. Internally, it has no detail or signal present. The trough shape mostly bounds to the long reflection above. Facies 5 can be interpret as a small channel. The small channel is a channel which has scour surface from bar-top hollows (Horn et al., 2012).

Facies 6.- Isolated concaved-up which bounded to the reflection boundaries or first order surface. Internally, facies 6 contains of hummocky/wave and sigmoid reflectors (Horn et al., 2012). This facies crosscutting is bigger than facies5. The shape of curved up may be symmetric or asymmetric. This channel can be longer than 20 m and has depth about 1–3 m.

Facies 7.- Facies 7 is parallel(planar). It formed by group of parallel reflection pattern. Generally, facies7 can see apparently by hierarchy of layers and long continue parallel signal. Facies7 considers as a horizontal sand beded, stratified horizontal bedding, sand lamination to thick bed or sheetflood sand (Shukla et al., 2008).

Facies8.- Facies 8 refers to buried objects. It can be weathering rock, or something else like logs or wood debris (Skelly et al., 2003). This is an object that may carried with the current or may exist here before it buried by sediments. Mostly, it shows a supposedly as a parabolic shape but sometime found it as a high angle one. This happen may be because of attenuated of reflection signal.

Table 5 Summary of radar facies line 1-8, with representative examples of radar data and their interpretation. Radar facies classification based on Vandenberghe and Overmeeren (1999) , Skelly et al. (2003), Lunt and Bridge (2004), Shukla et al. (2008) and Horn et al. (2012)

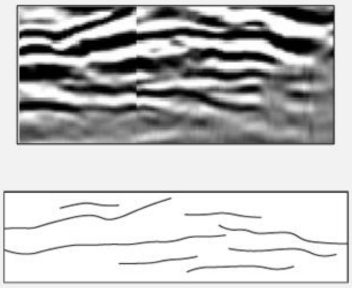
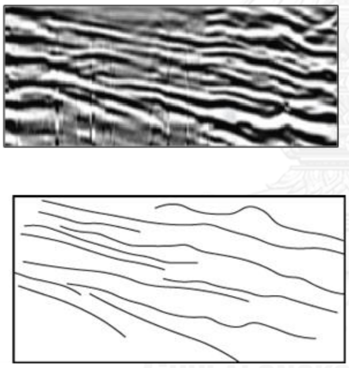
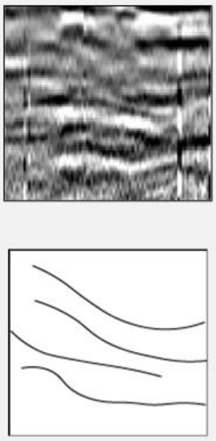
Facies no.	Radar Facies	Description	Interpretation
1		-Hummocky/wavy reflection -group of discontinue	-trough cross beds -sand bed -channel fills (overlie the curved) -deposition -side bar deposit (underneath the curved)
2		-Curved down pattern like shingled -group of inclined reflection - Reflection angel is about 15 – 45 degrees	-slipface of migration bedform -lateral accretion -downstream migration
3		Sets of en-echelon or sigmoid	-migrating of channel bar -possible set of unit bar

Table5 (Continue)

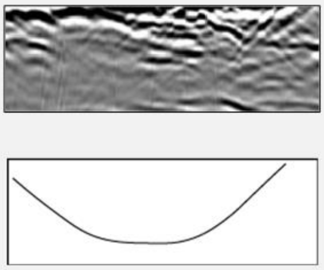
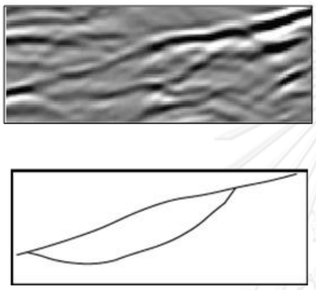
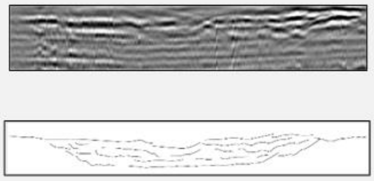
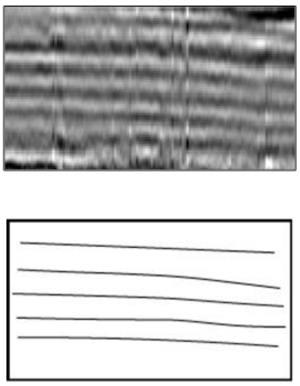
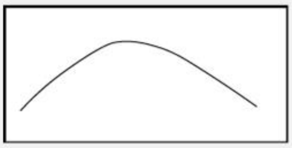
Facies no.	Radar Facies	Description	Interpretation
4		-Concave-up or curved	-erosion surface -may be channel
5		-Isolated trough shape may symmetric or asymmetric	-small channel
6		-Isolated concaved-up which bounded to the reflection boundaries or first order surface - trough shape may symmetric or asymmetric	Secondary channel scours and fills
7		Parallel, horizontally continuous, layered	-horizontal sand beded or stratified horizontal bedding -sand lamination to thick bed -sheetflood sand

Table5 (Continue)

Facies no.	Radar Facies	Description	Interpretation
8	 	-parabolic	-weathering rock -buried object (e.g. log, wood, debris)

4.5.2 GPR Interpretation Result

8 GPR survey lines were interpreted follow by the radar facies in table5. The unique characteristic of each GPR facies uses to identify the signal and defines the complex structure. Moreover, the interpretation is based on point bar environment. With definition from the reference, GPR radar facies and surface data, the interpretation shows in figure 30 – 57

Line 1 from site no. 1

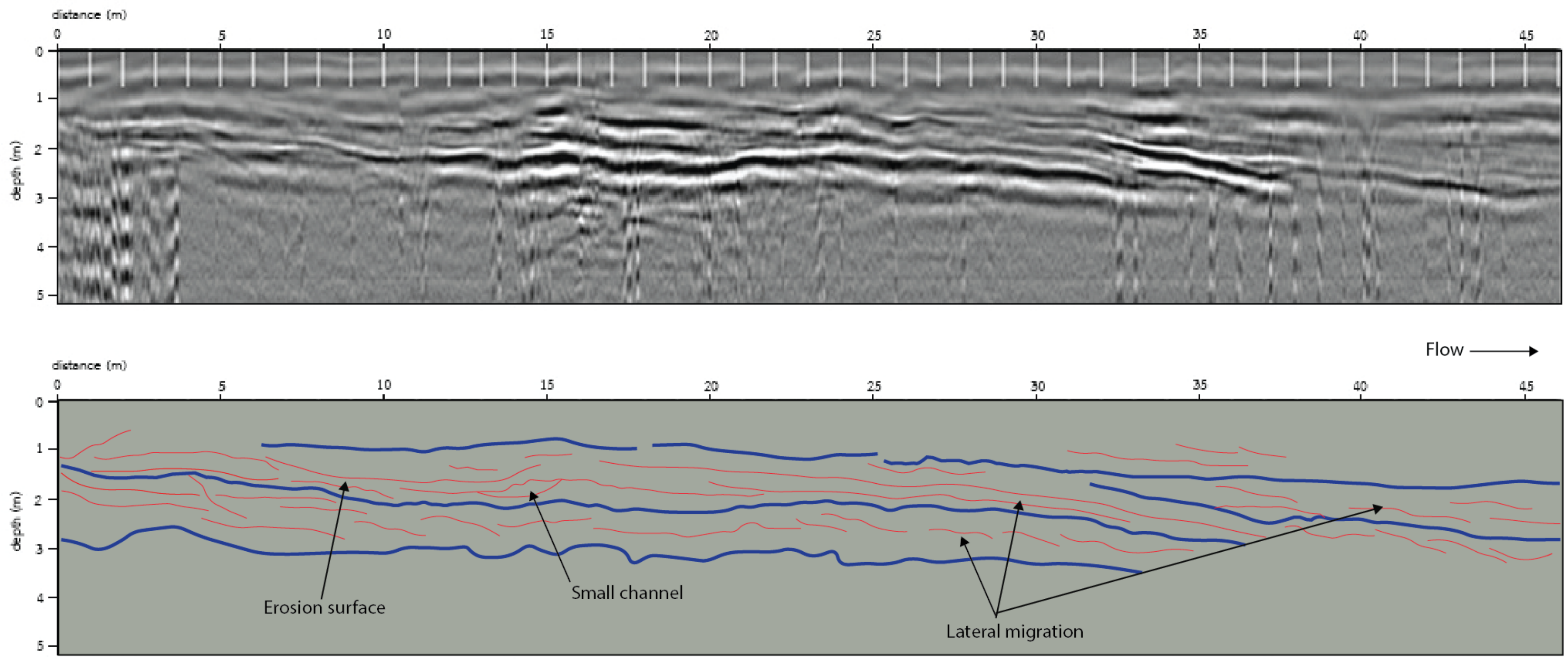


Figure 30 GPR signal and interpretation sketch of GPR Survey line 1 from site no.1 at 0-45 m.

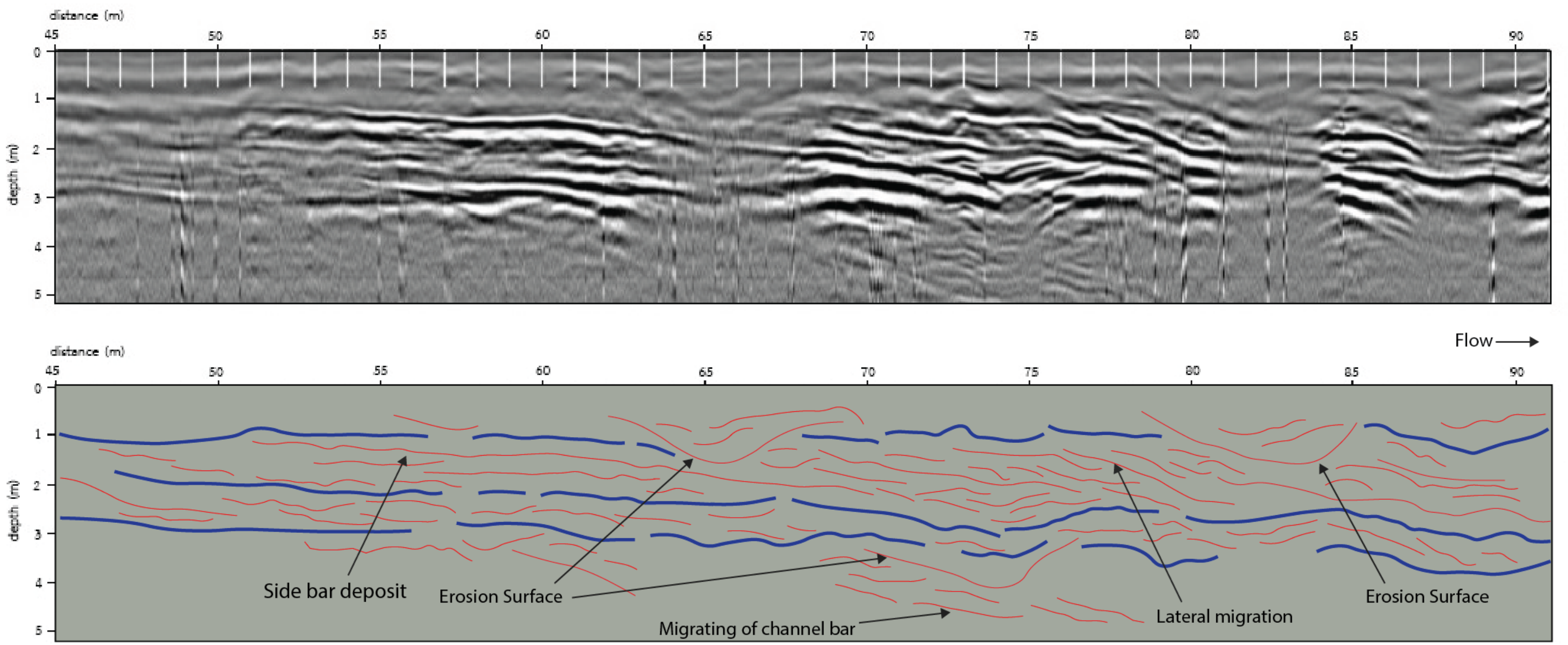


Figure 31 GPR signal and interpretation sketch of GPR Survey line 1 from site no.1 at 45 – 90 m.

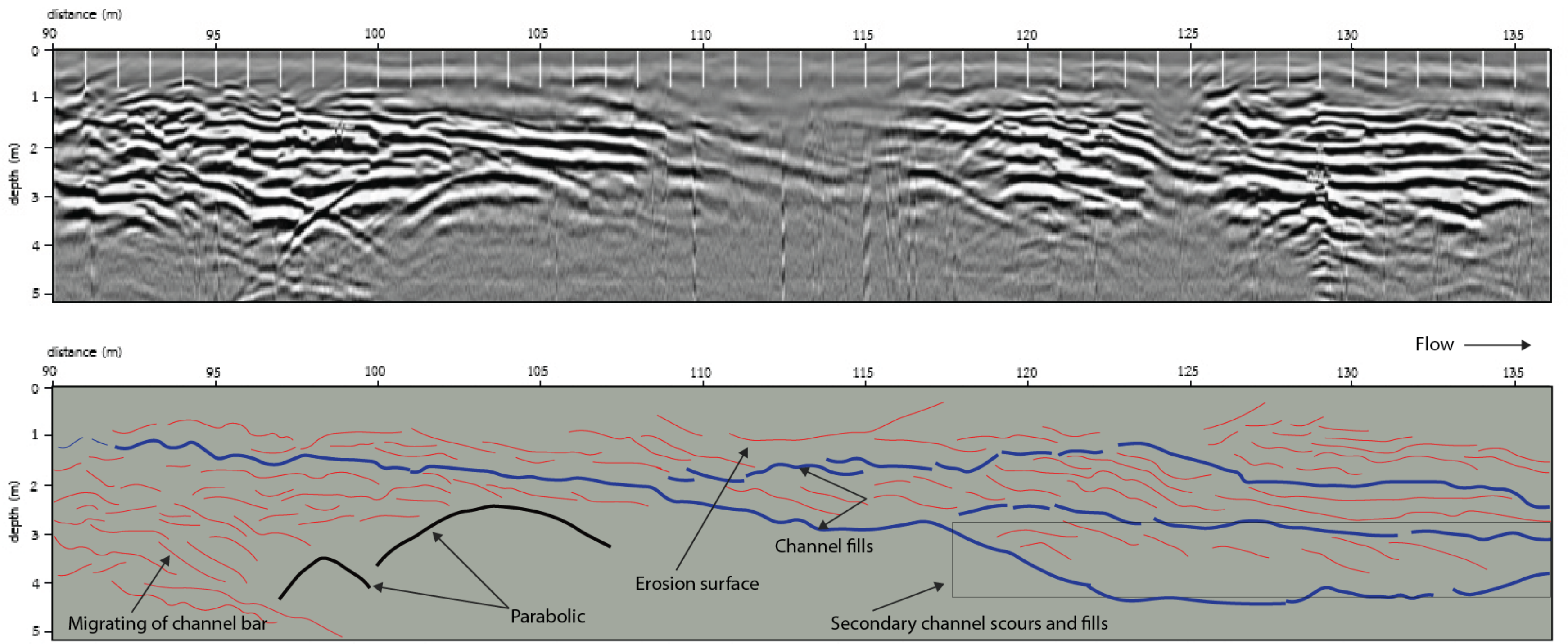


Figure 32 GPR signal and interpretation sketch of GPR Survey line 1 from site no.1 at 90 - 135 m.

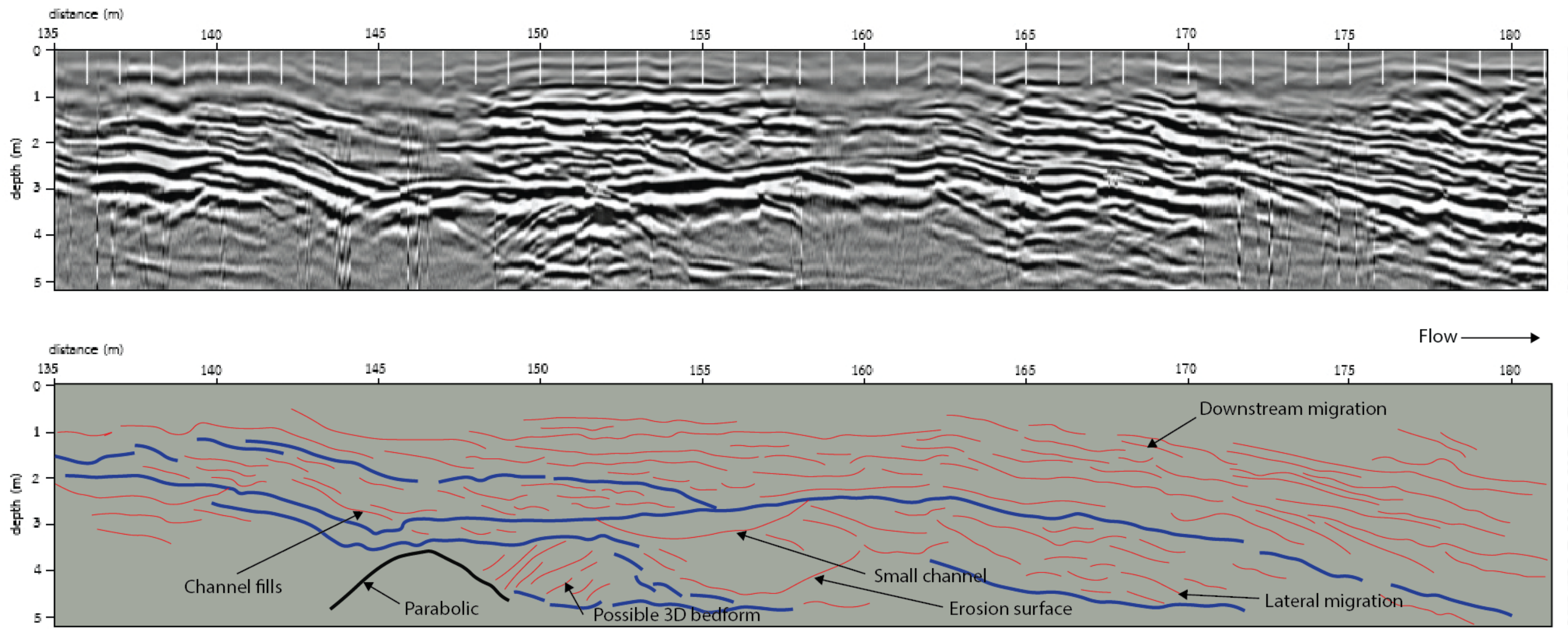


Figure 33 GPR signal and interpretation sketch of GPR Survey line 1 from site no.1 at 135 - 180 m.

Line 2 from site no. 1

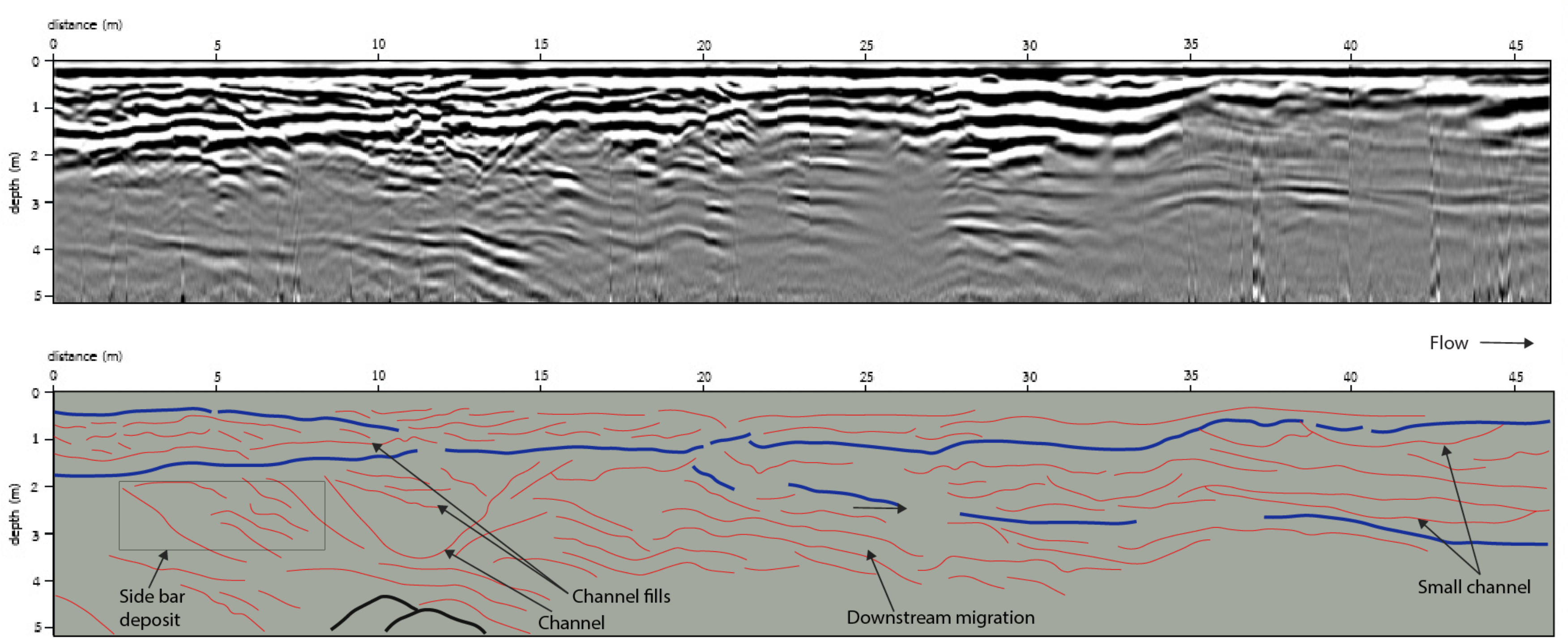


Figure 34 GPR signal and interpretation sketch of GPR Survey line 2 from site no.1 at 0-45 m

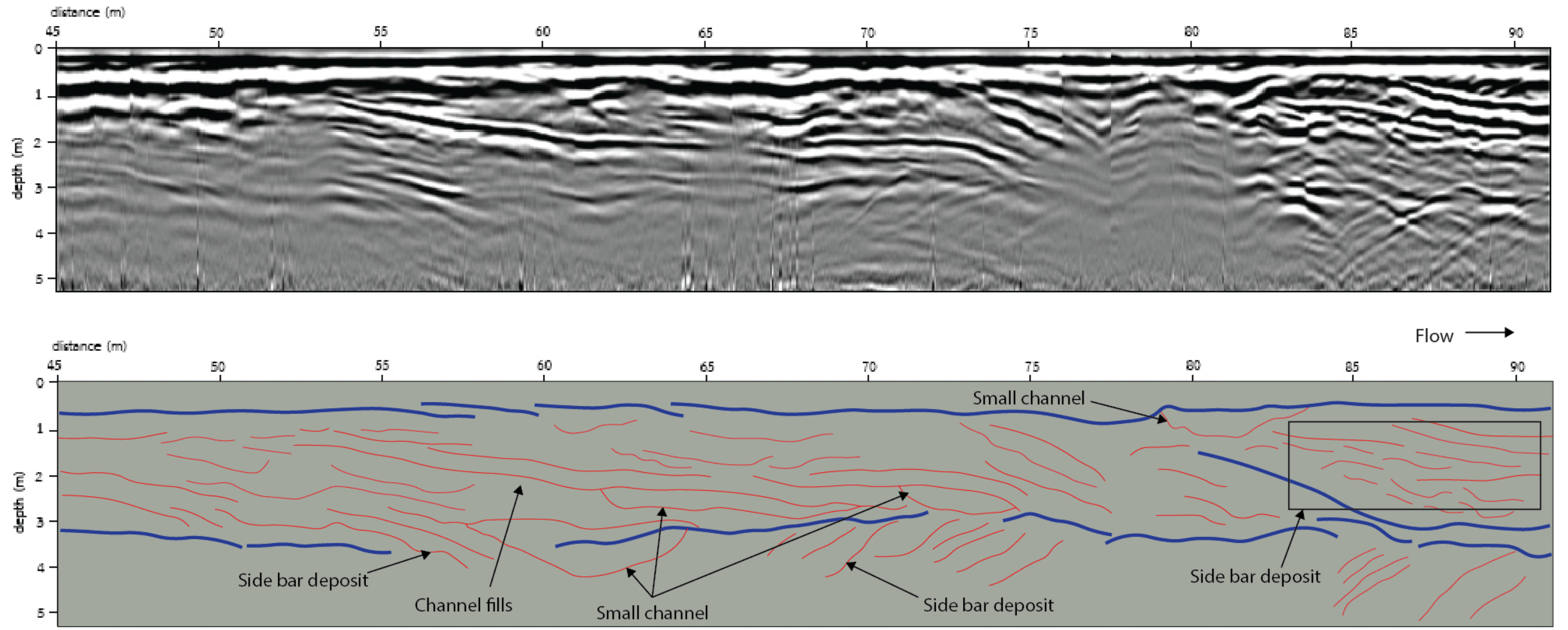


Figure 35 GPR signal and interpretation sketch of GPR Survey line 2 from site no.1 at 45 - 90 m.

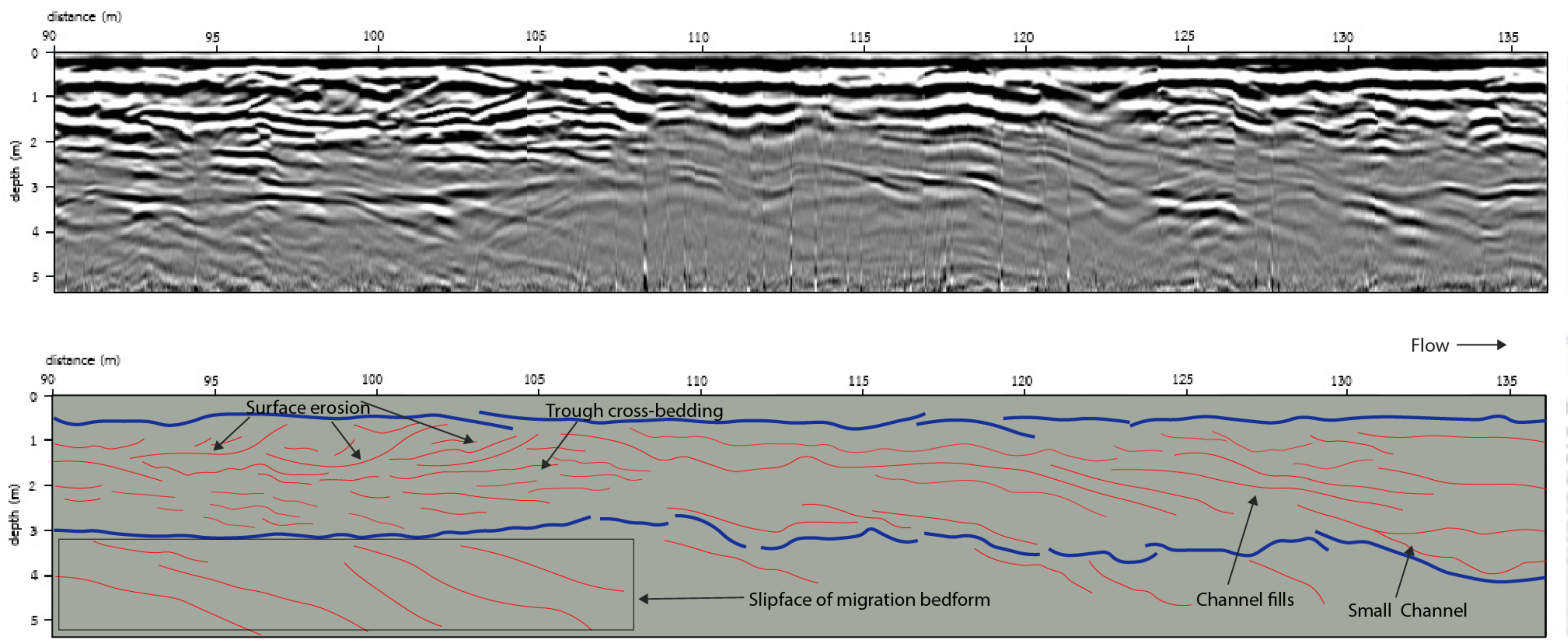


Figure 36 GPR signal and interpretation sketch of GPR Survey line 2 from site no.1 at 90 - 135 m.

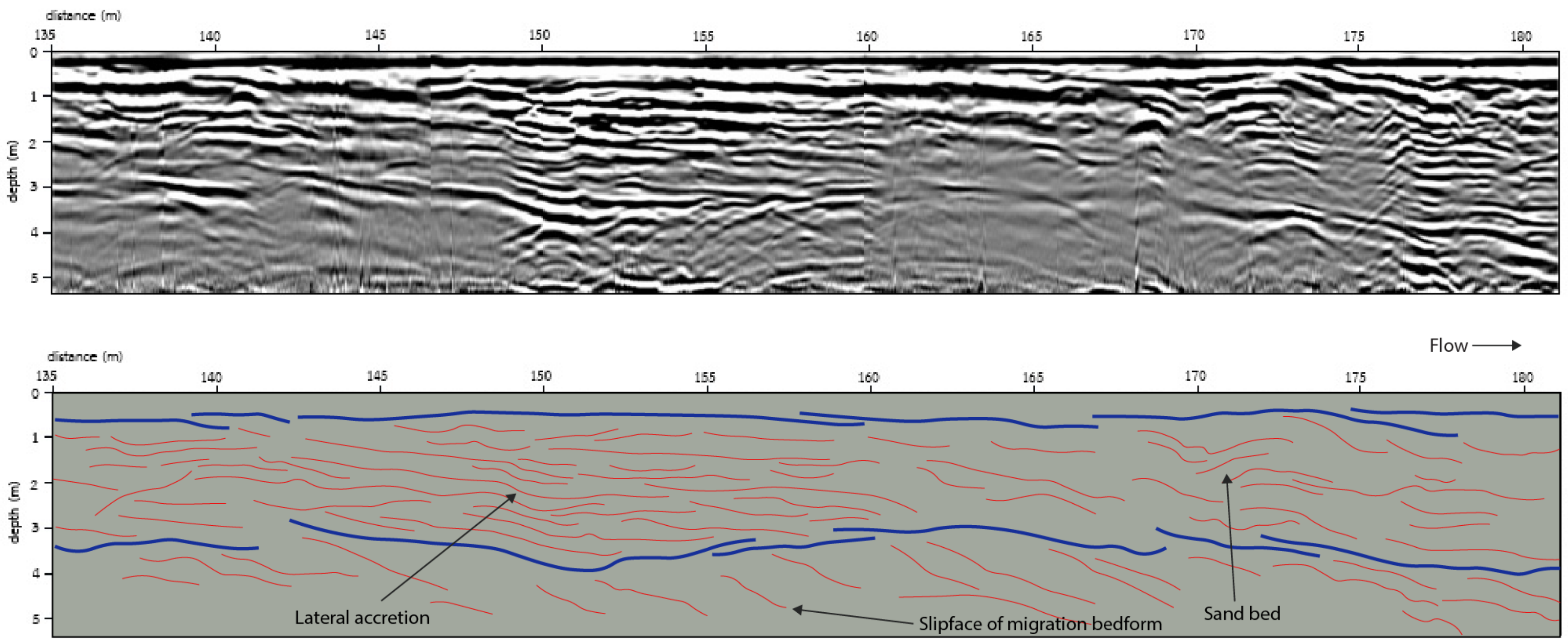


Figure 37 GPR signal and interpretation sketch of GPR Survey line 2 from site no.1 at 135 - 180 m.

Line 3 from site no. 1

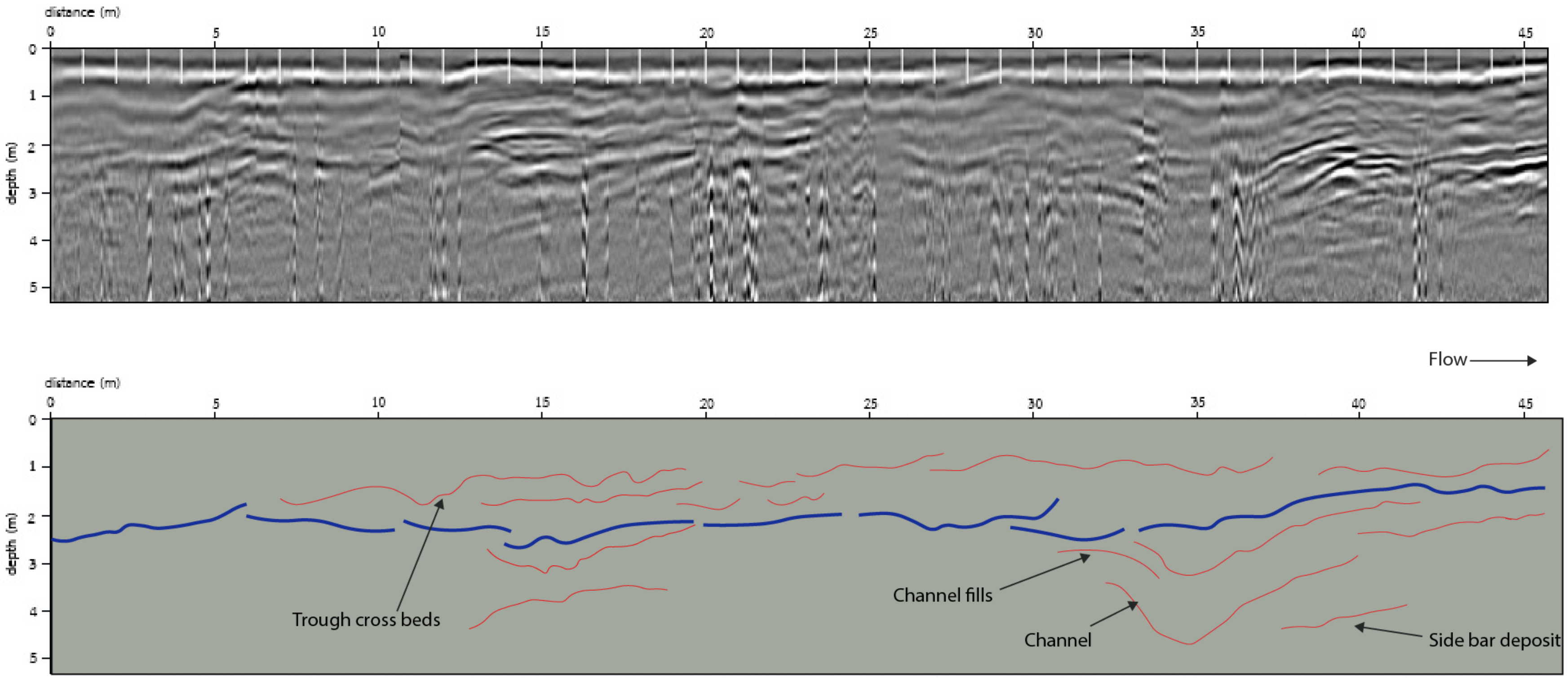


Figure 38 GPR signal and interpretation sketch of GPR Survey line 3 from site no.1 at 0-45 m.

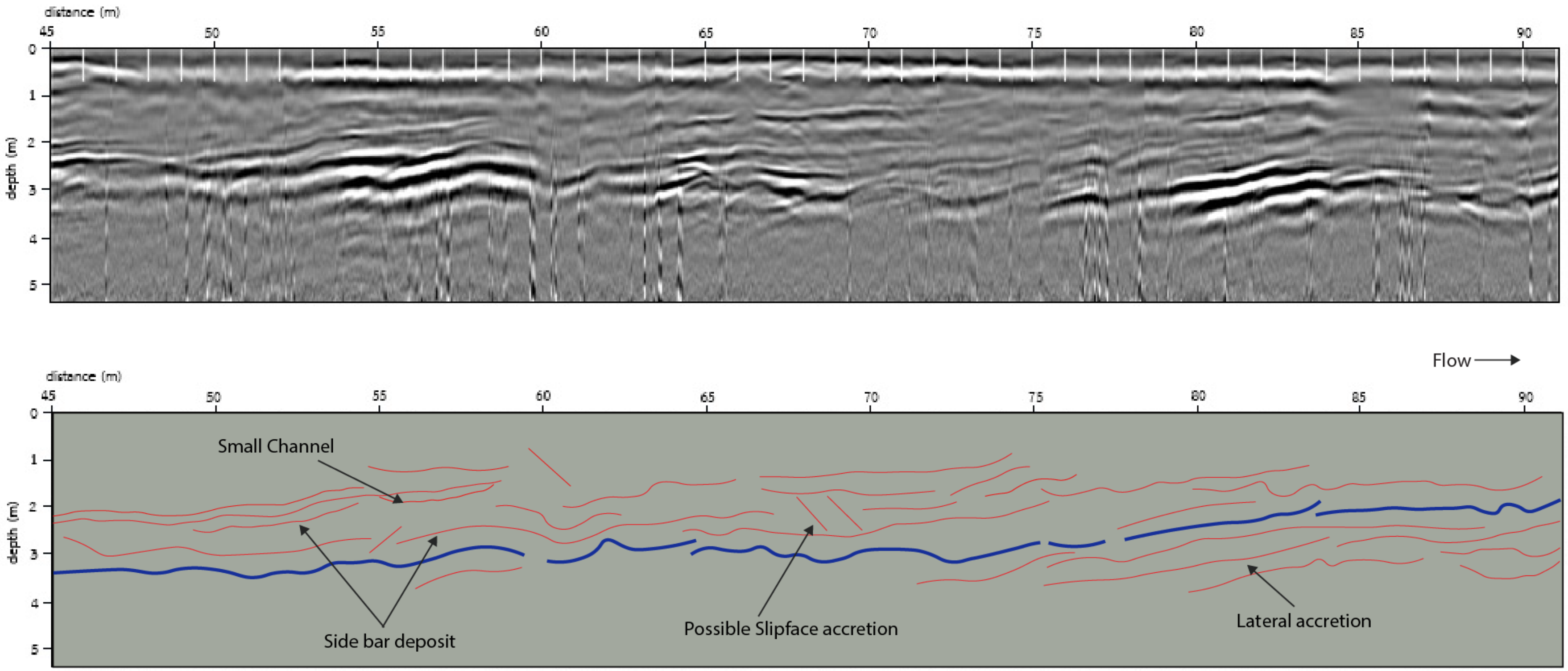


Figure 39 GPR signal and interpretation sketch of GPR Survey line 3 from site no.1 at 45 - 90 m.

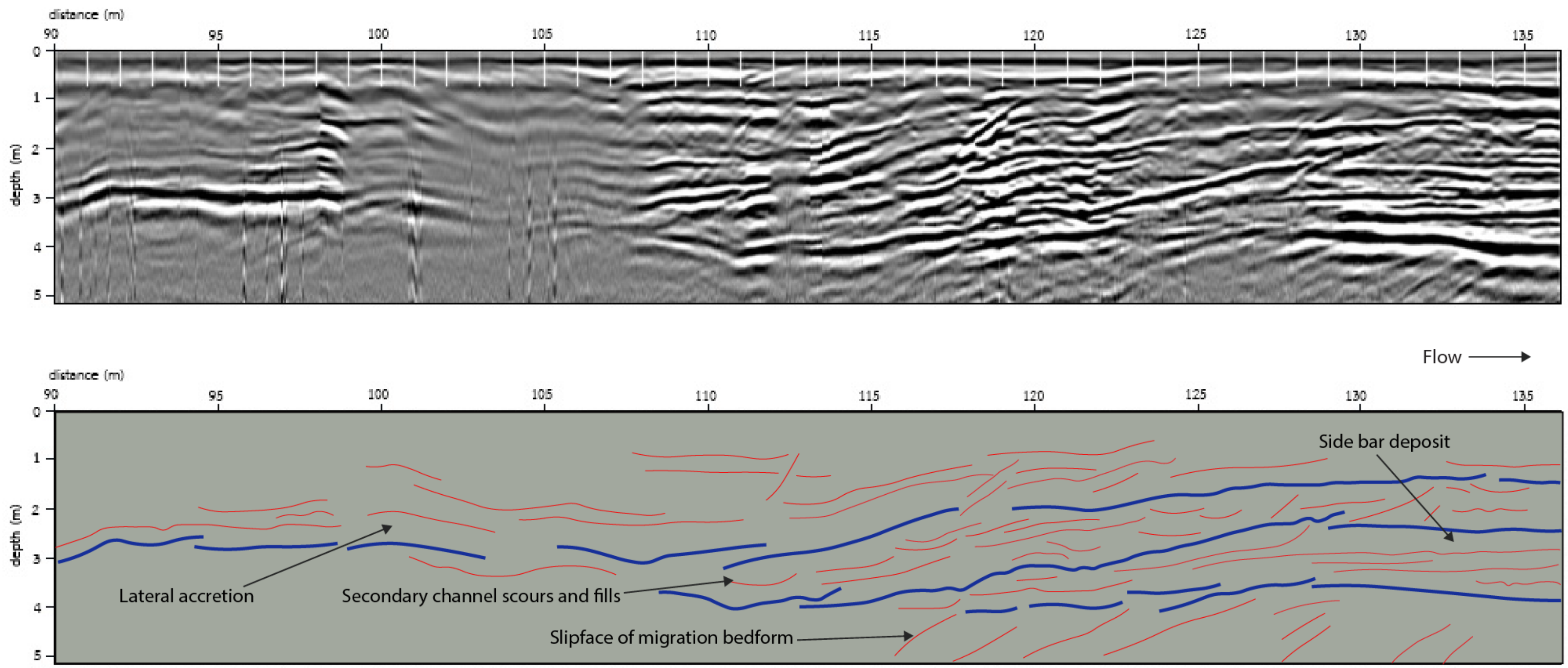


Figure 40 GPR signal and interpretation sketch of GPR Survey line 3 from site no.1 at 90 - 135 m.

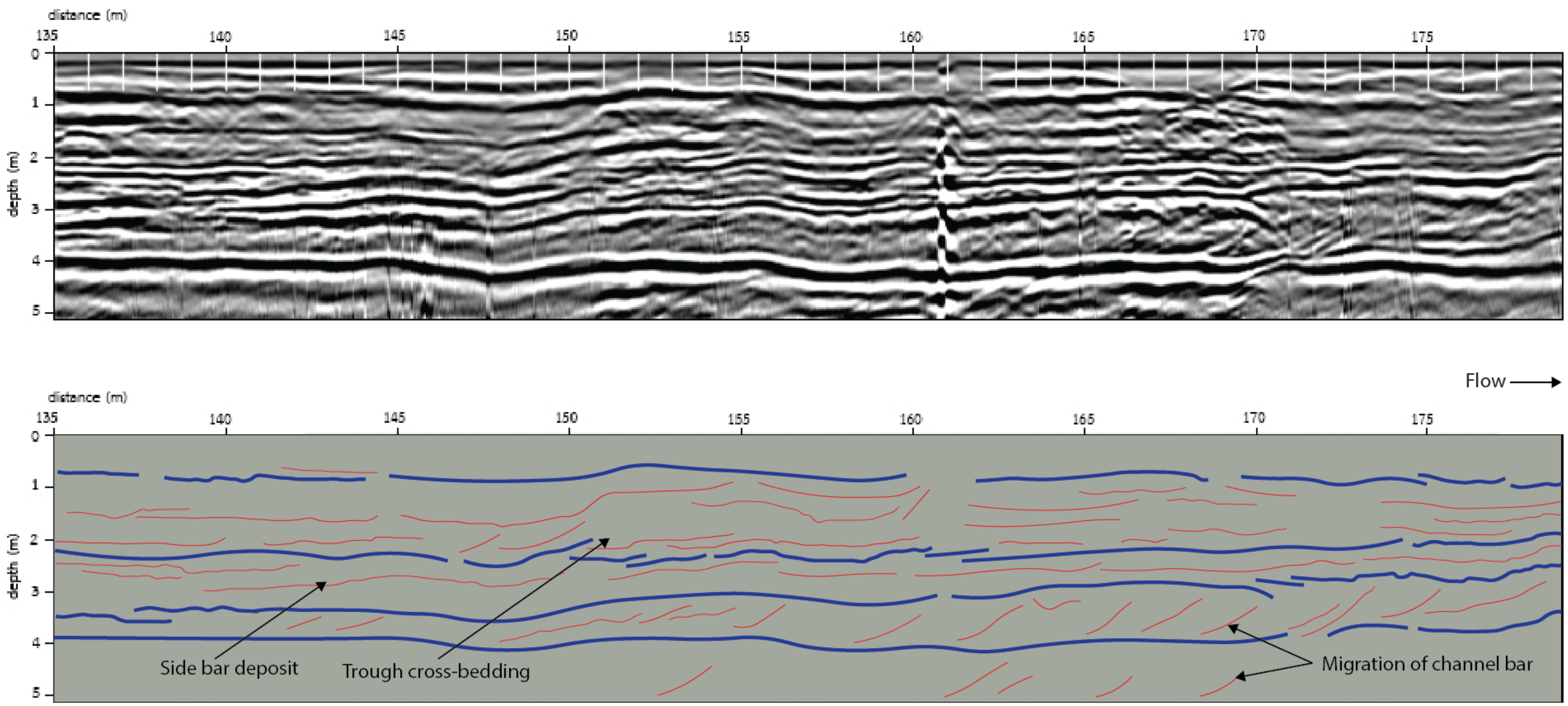


Figure 41 GPR signal and interpretation sketch of GPR Survey line 3 from site no.1 at 135 - 175 m.

Line 4 from site no. 1

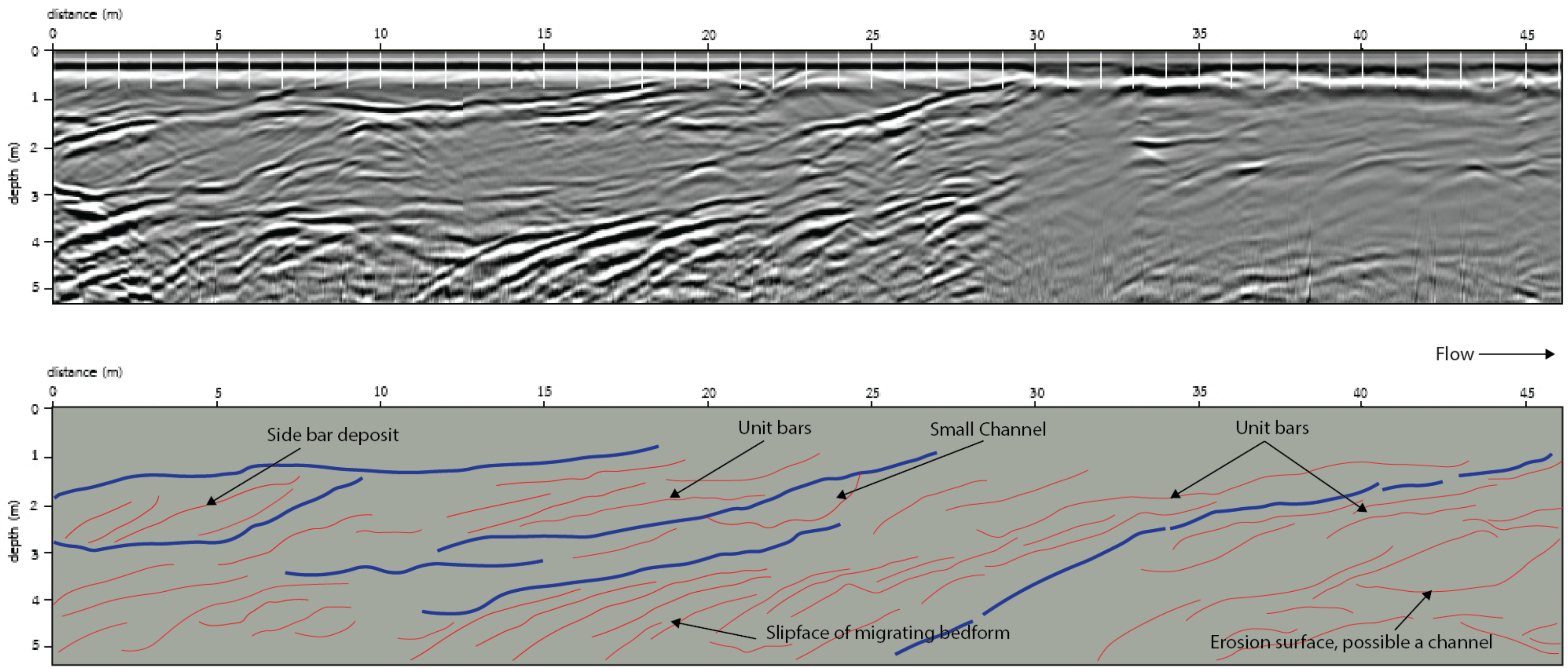


Figure 42 GPR signal and interpretation sketch of GPR Survey line 4 from site no.1 at 0 - 45 m.

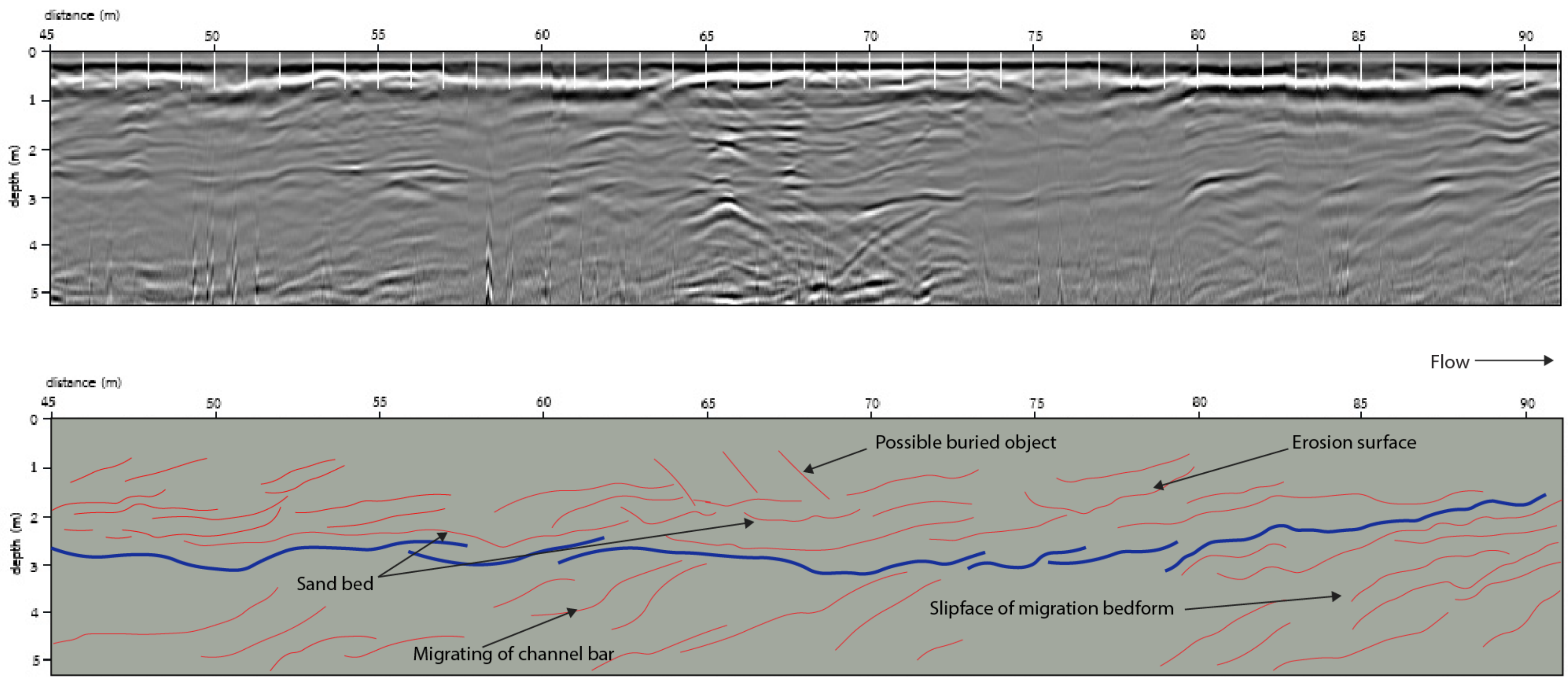


Figure 43 GPR signal and interpretation sketch of GPR Survey line 4 from site no.1 at 45 - 90 m.

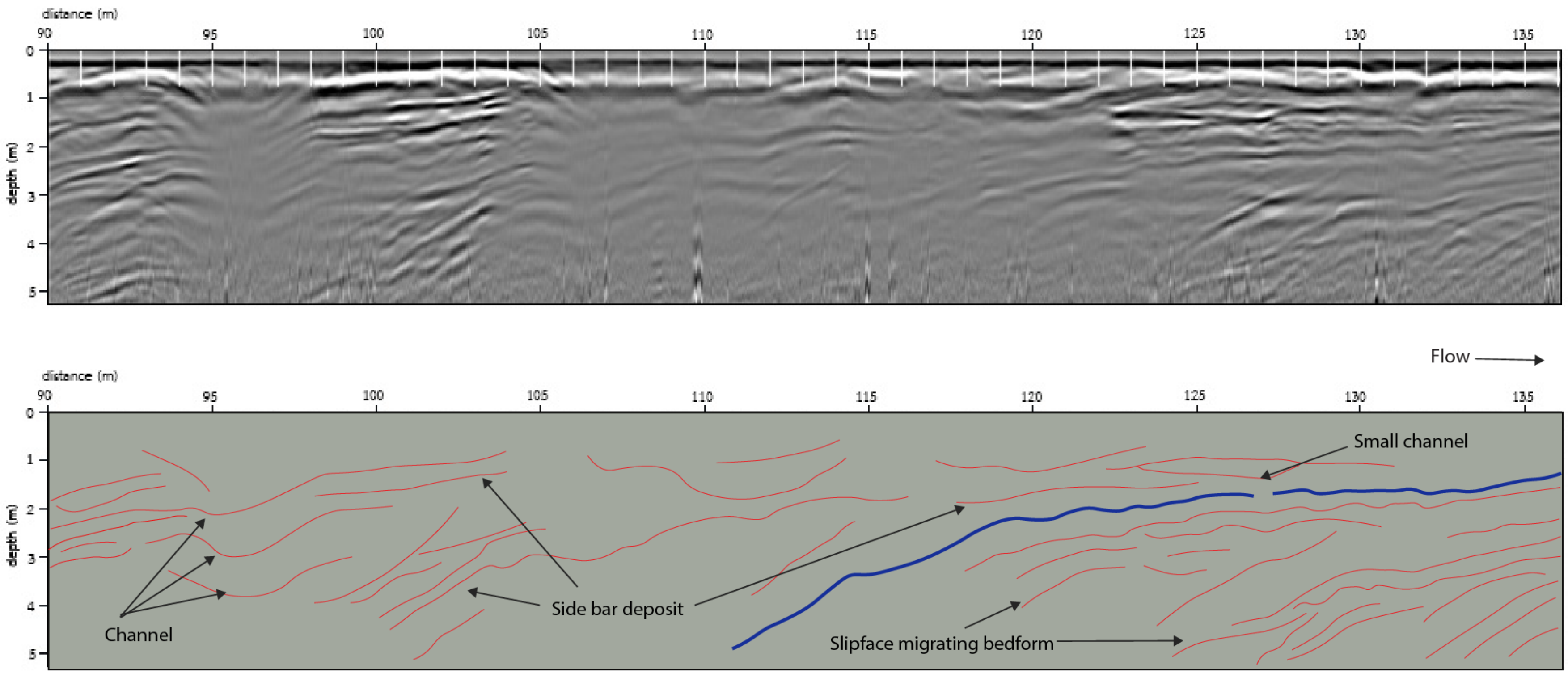


Figure 44 GPR signal and interpretation sketch of GPR Survey line 4 from site no.1 at 90 - 135 m.

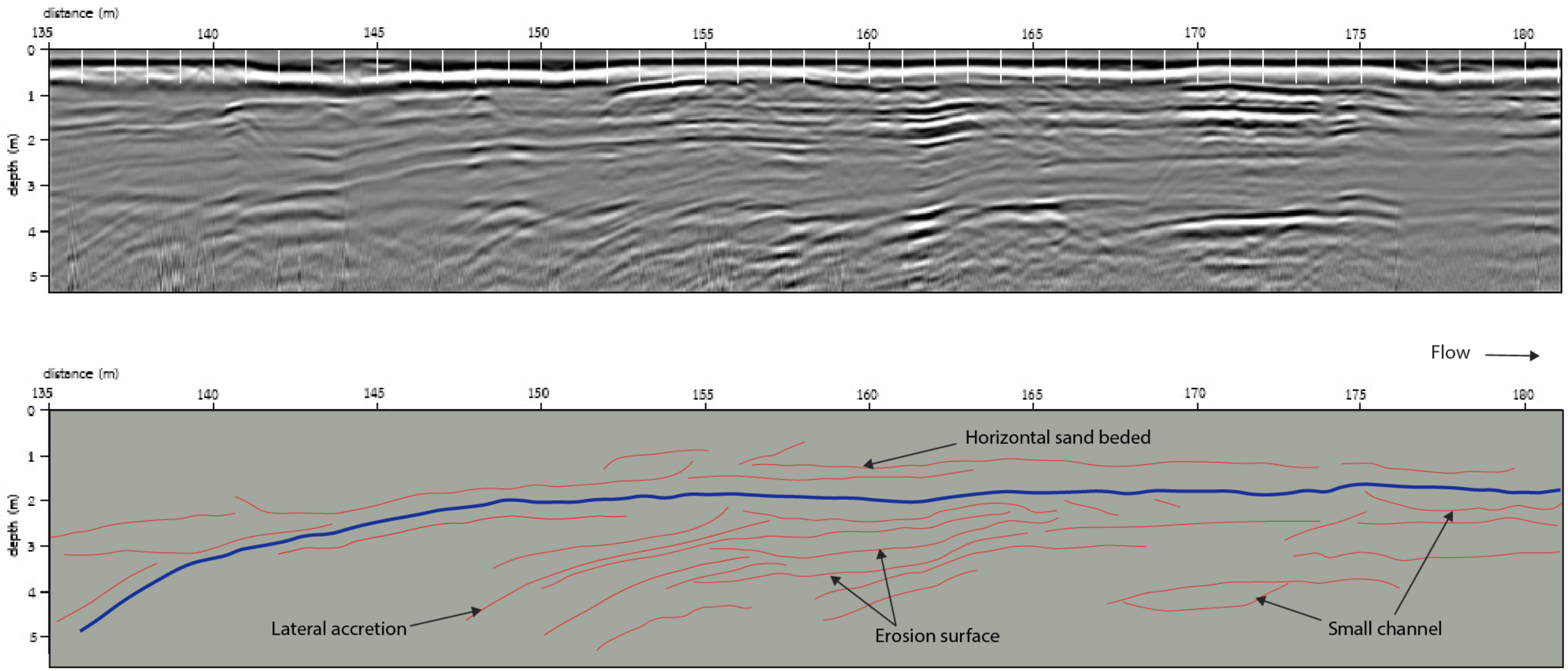


Figure 45 GPR signal and interpretation sketch of GPR Survey line 4 from site no.1 at 135 - 180 m.

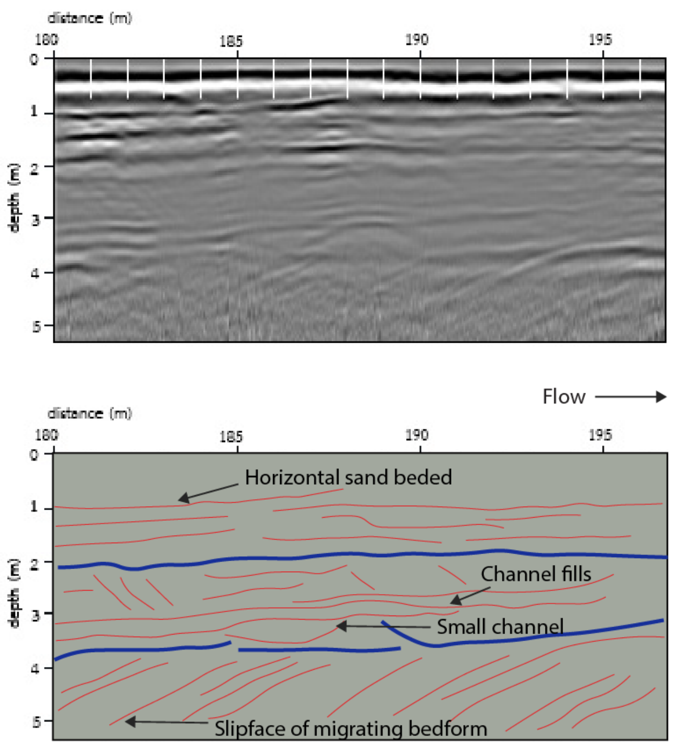
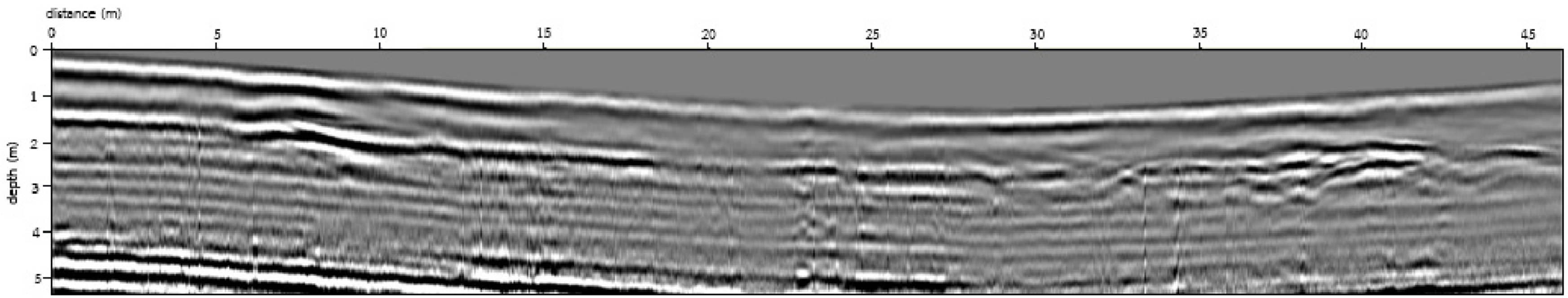


Figure 46 GPR signal and interpretation sketch of GPR Survey line 4 from site no.1 at 180 - 195 m.

Line 5 from site no. 1



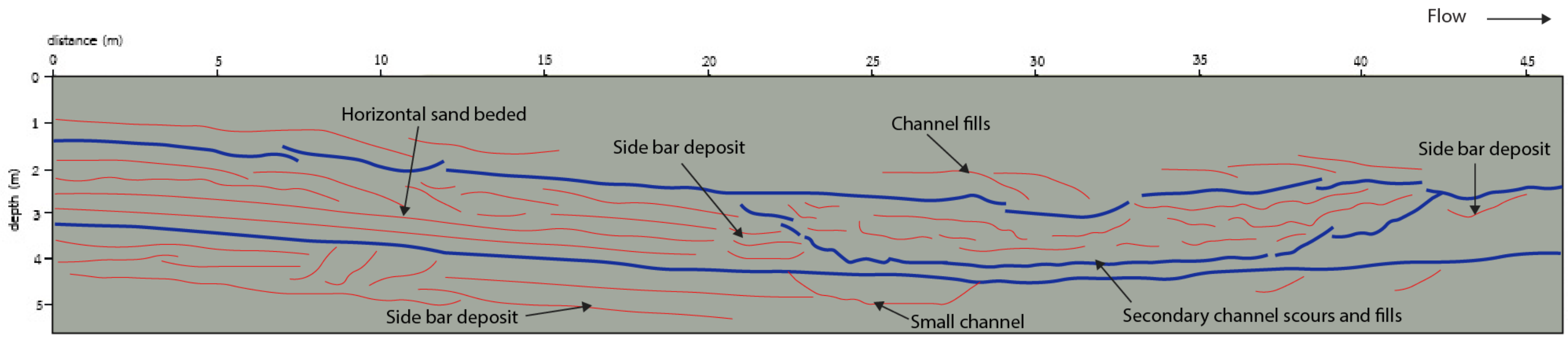


Figure 47 GPR signal and interpretation sketch of GPR Survey line 5 from site no.1 at 0 - 45 m.

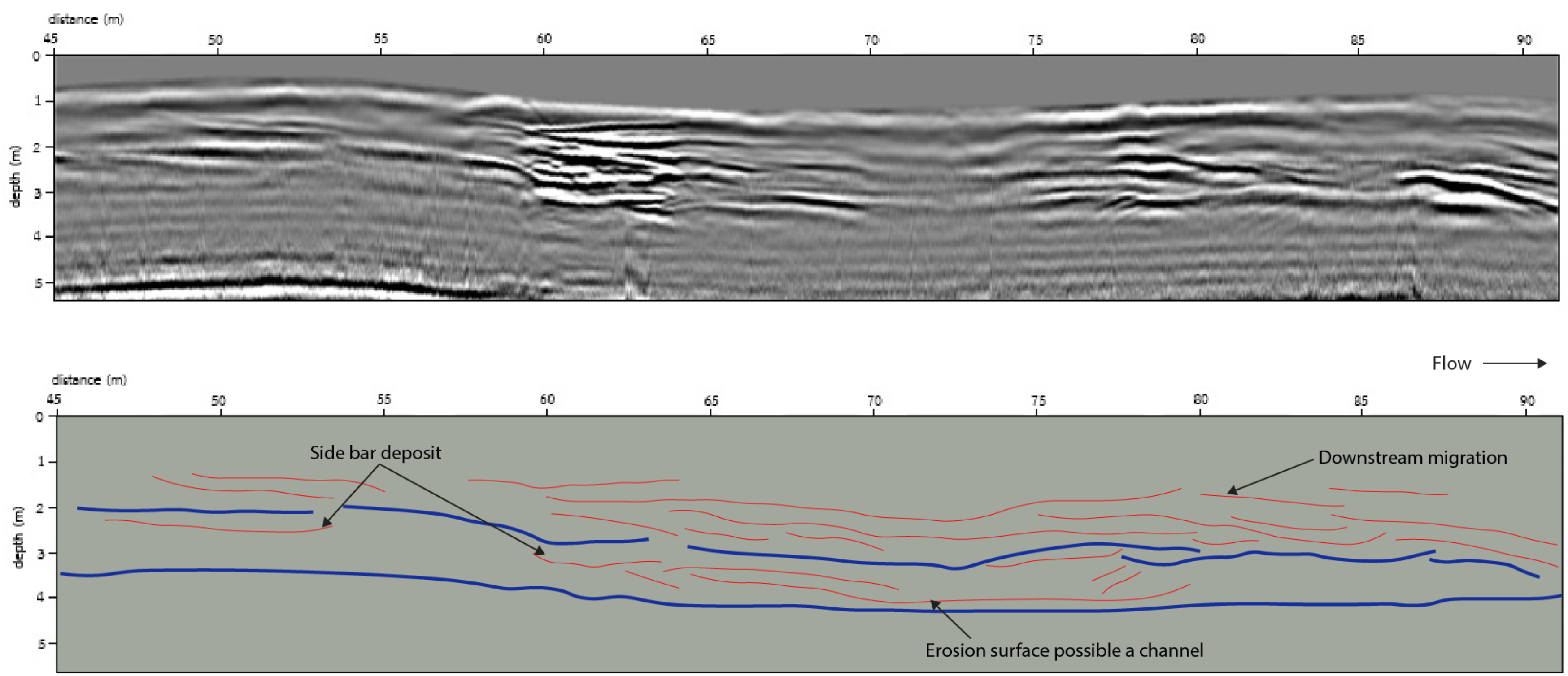


Figure 48 GPR signal and interpretation sketch of GPR Survey line 5 from site no.1 at 45 - 90 m.

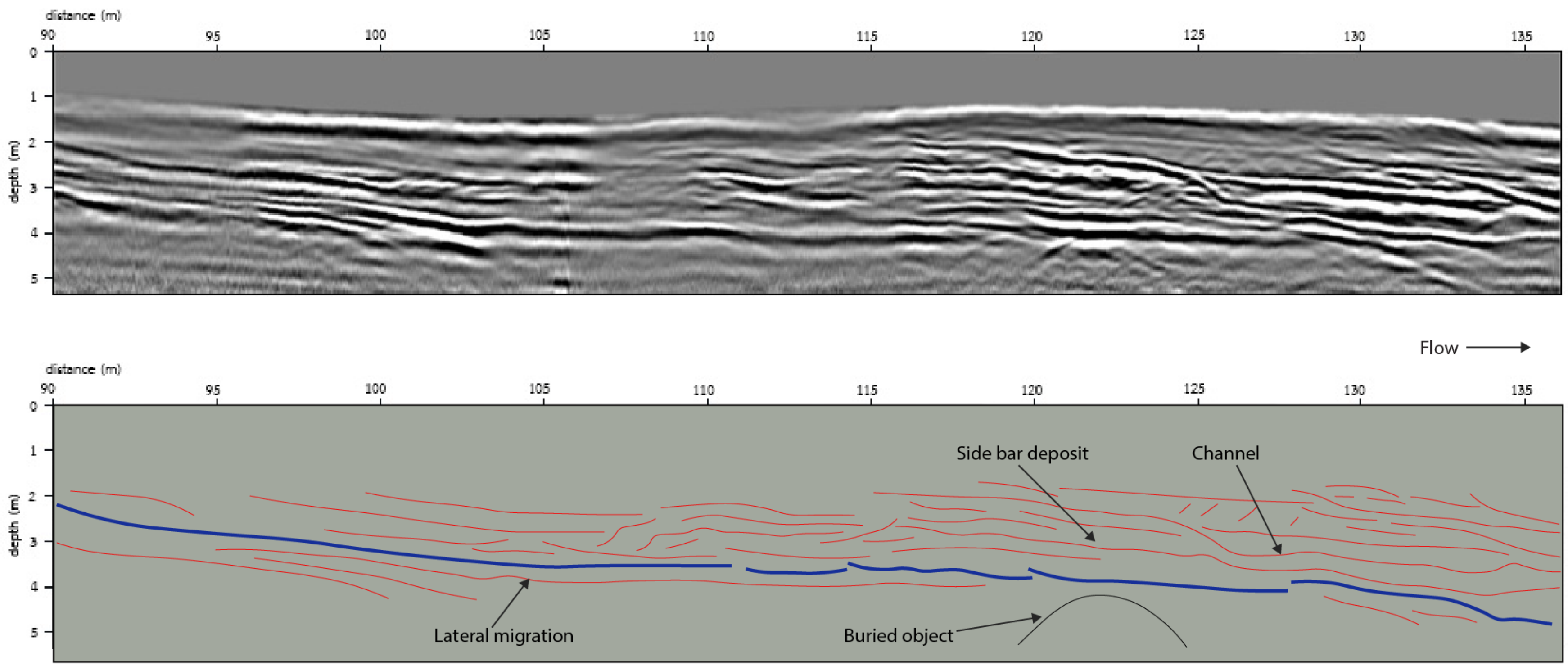


Figure 49 GPR signal and interpretation sketch of GPR Survey line 5 from site no.1 at 90 - 135 m.

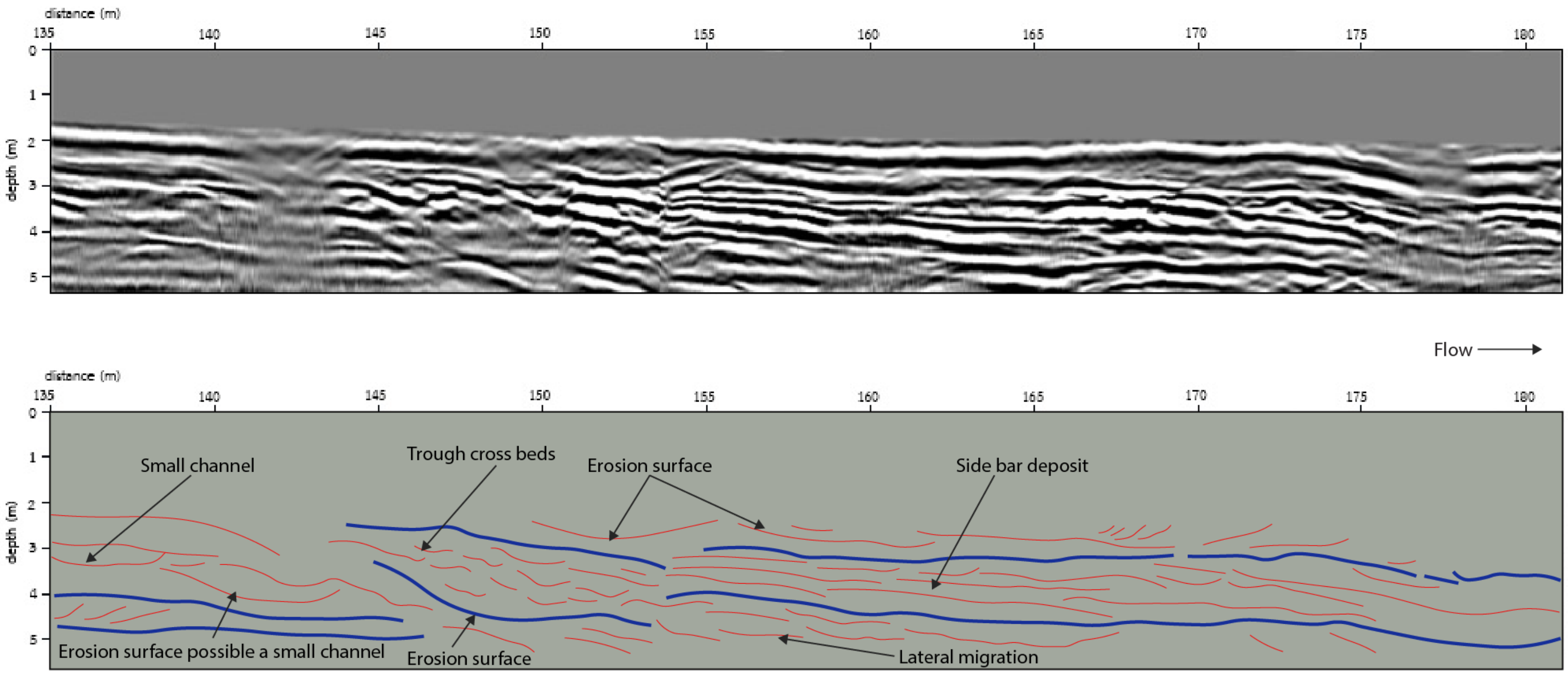


Figure 50 GPR signal and interpretation sketch of GPR Survey line 5 from site no.1 at 135 - 180 m.

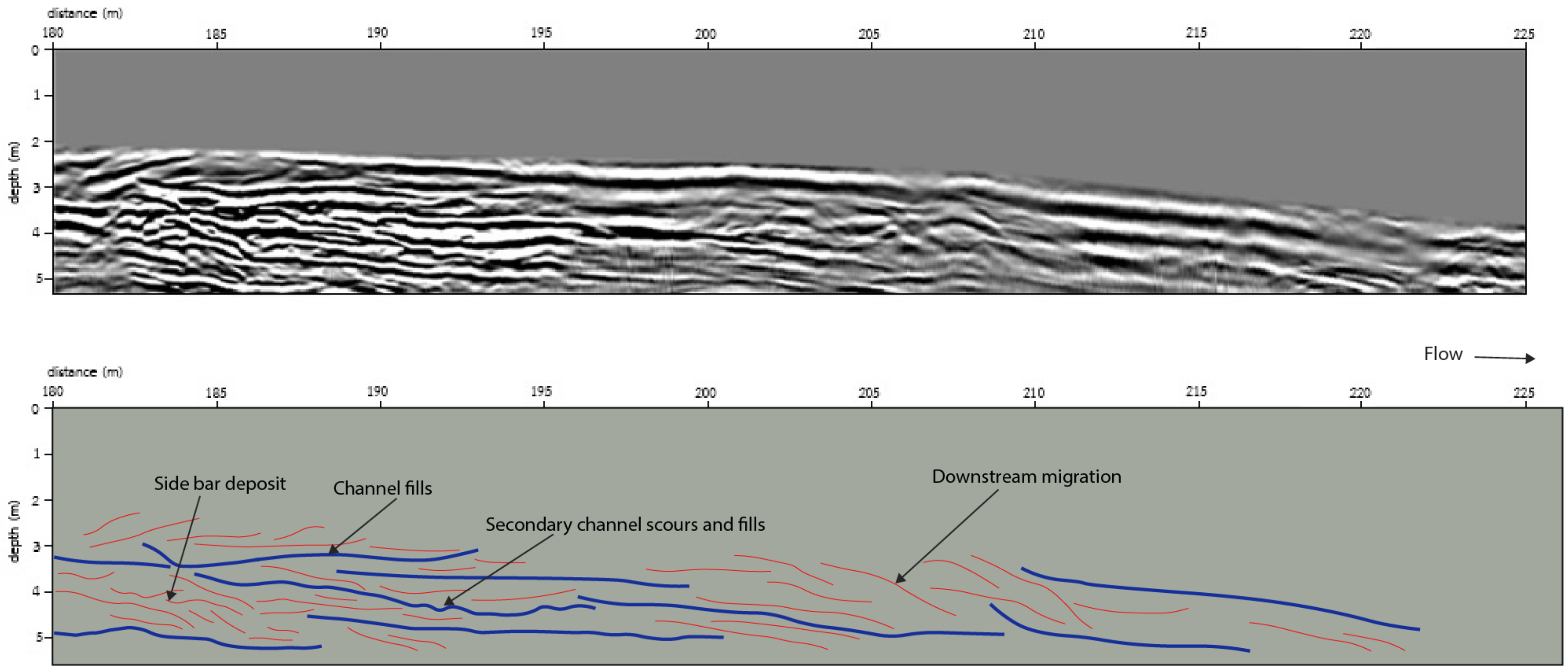


Figure 51 GPR signal and interpretation sketch of GPR Survey line 5 from site no.1 at 180 - 225 m.

Line 6 from site no. 2

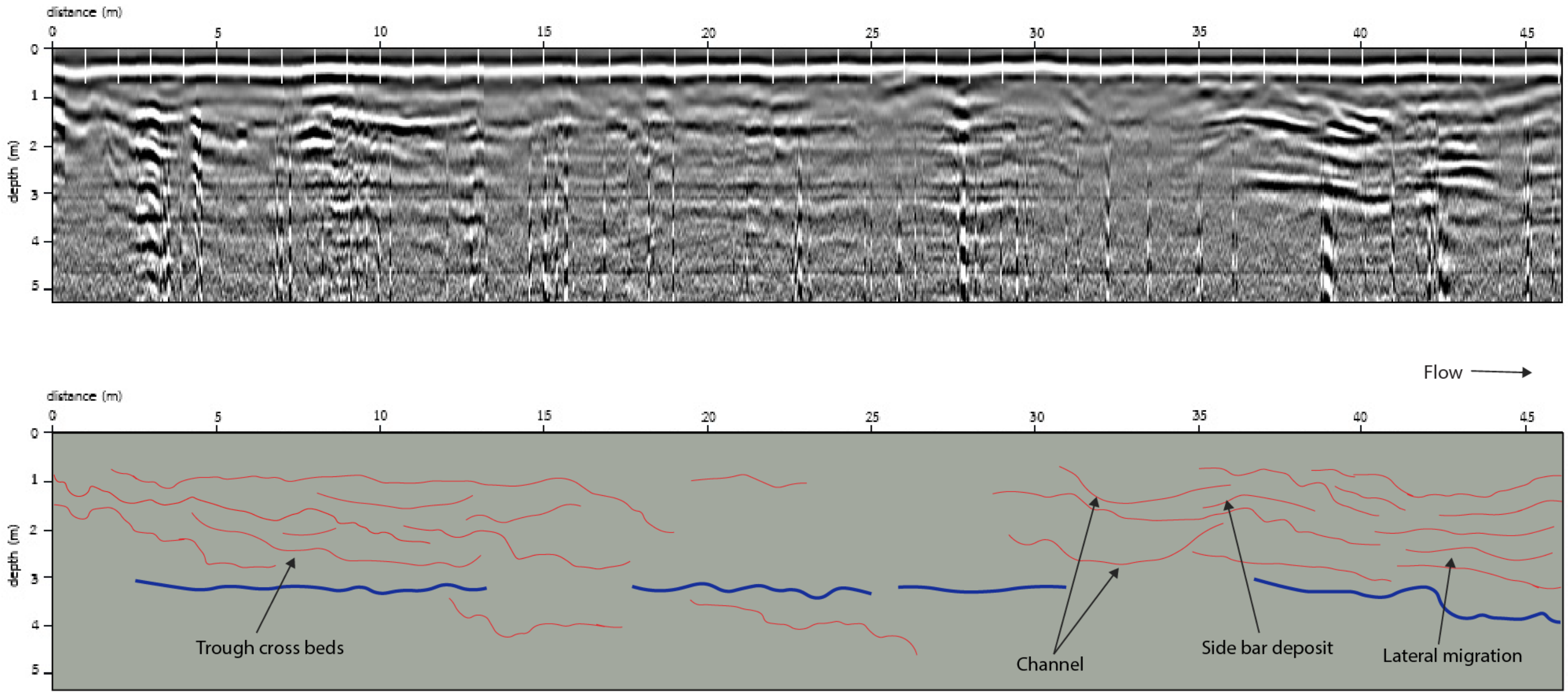


Figure 52 GPR signal and interpretation sketch of GPR Survey line 6 from site no.2 at 0 - 45 m.

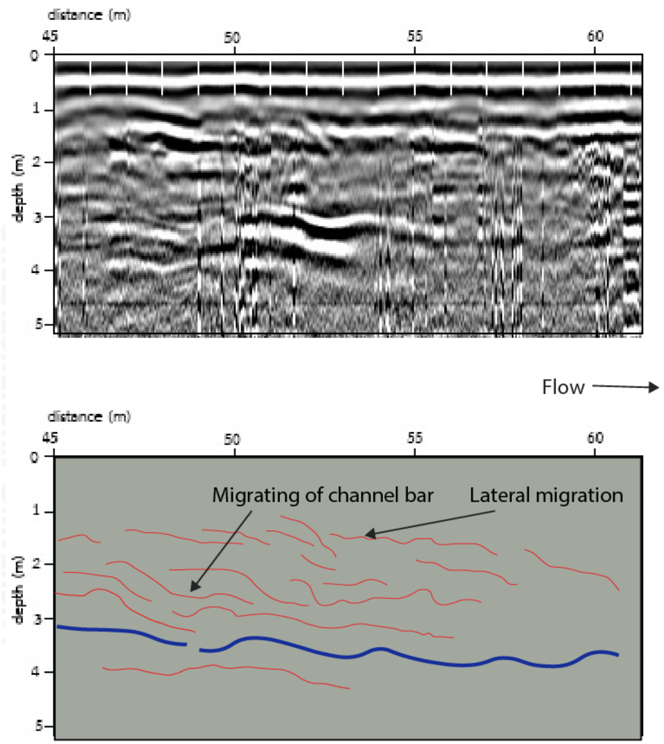


Figure 53 GPR signal and interpretation sketch of GPR Survey line 6 from site no.2 at 45 - 60 m.

Line 7 from site no. 2

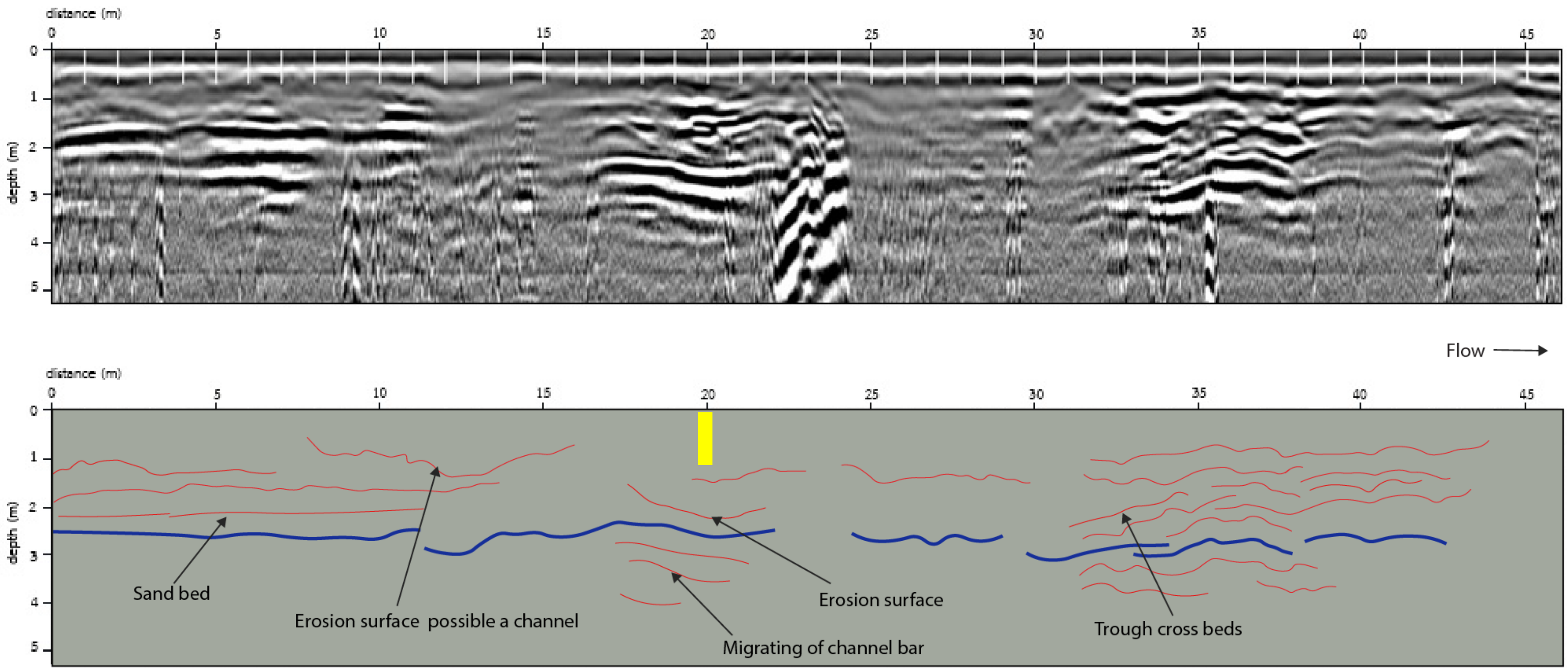


Figure 54 GPR signal and interpretation sketch of GPR Survey line 7 from site no.2 at 0 - 45 m.

(Yellow shape represents profile collecting location.)

Line 8a from site no. 2

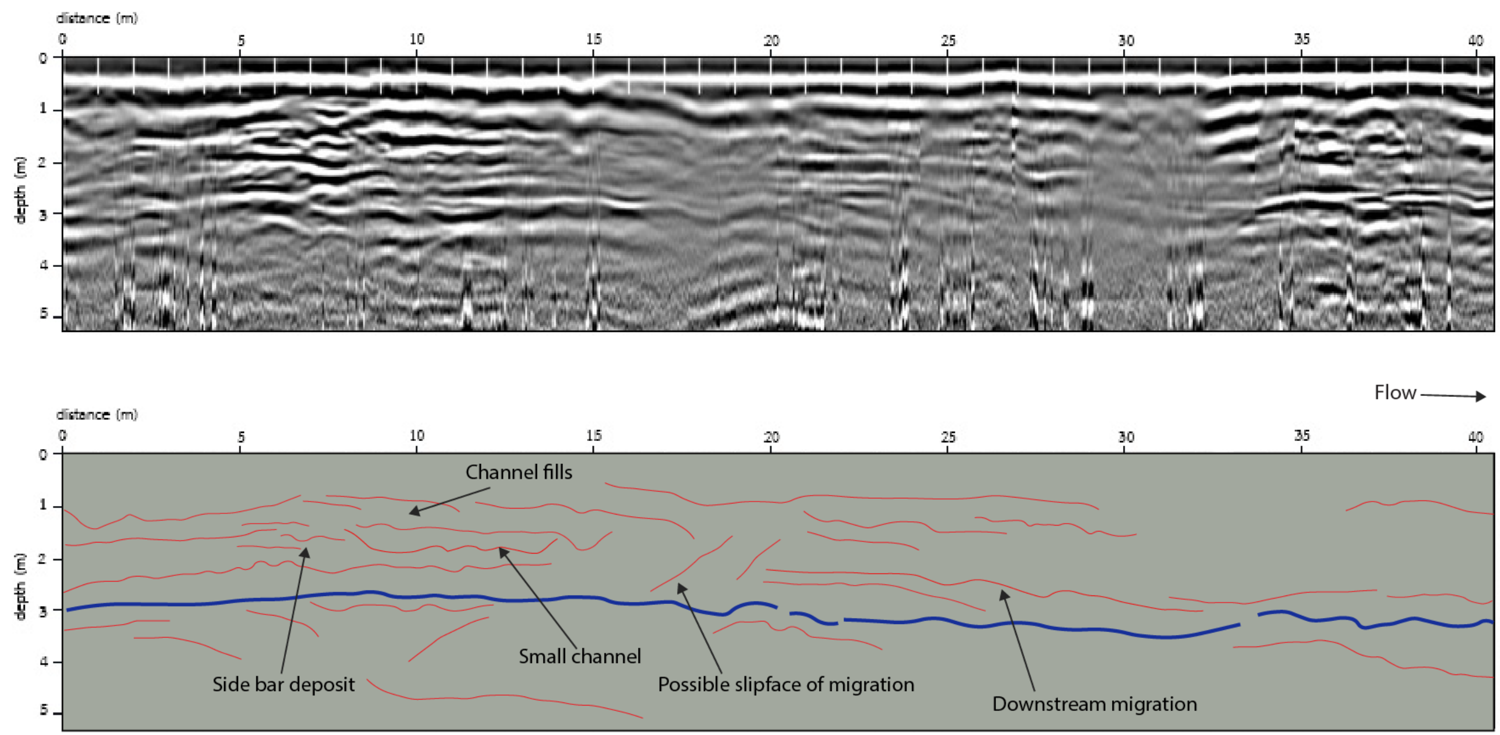


Figure 55. GPR signal and interpretation sketch of GPR Survey line 8a from site no.2 at 0 - 40 m.

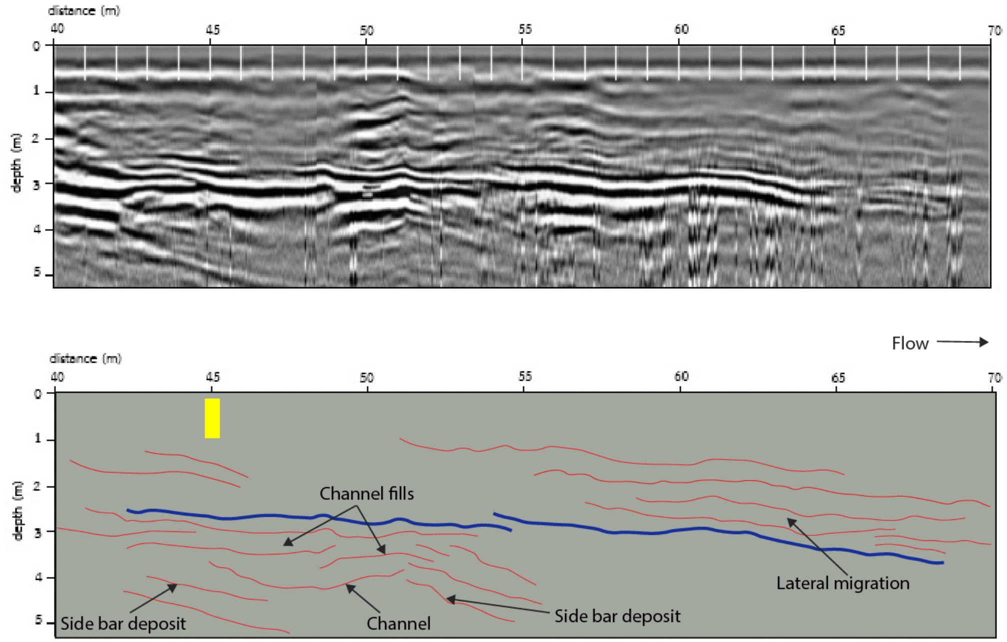


Figure 56 GPR signal and interpretation sketch of GPR Survey line 8a from site no.2 at 40 - 70 m.

(Yellow shape represents profile collecting location.)

Line 8b from site no. 2

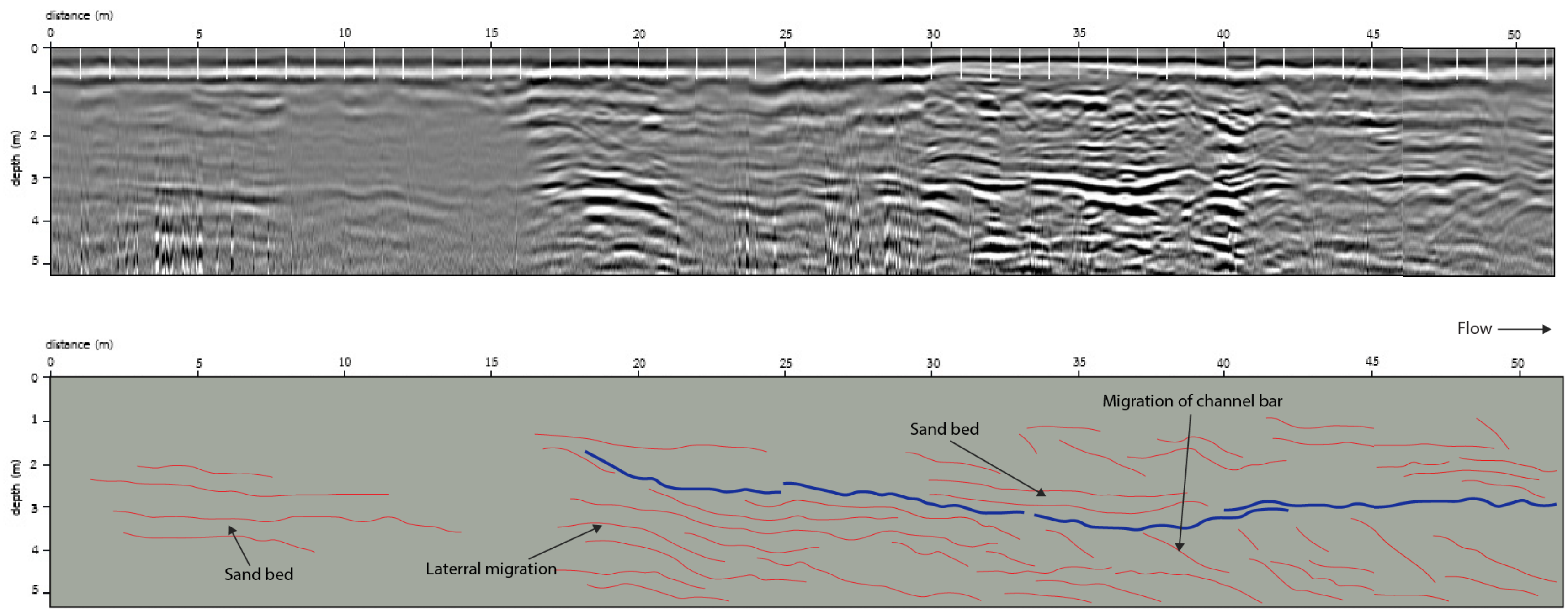


Figure 57 GPR signal and interpretation sketch of GPR Survey line8b from site no.2 at 0 - 50 m.

4.5.2 Profile

3 profiles including bank profile (location from figure16), line 7's profile and line 8a's profile are collecting for help to prove the GPR interpretation. All profile were sketched for propose to present the primary architecture of fluvial deposits structure. Also, they had determined the lithofacies for classify and group deposit layers.

The lithofacies used symbol and classified detail from Miall (1977) and some details from Choowong (1996) and Duangkrayom et al. (2014). This area is dominated by 3 lithofacies which are St, Sl and Sh. All of them are facies that dominated by sand. St defined as trough cross and wedge- shaped bedded sand. This facies shows the incision of concave-up shaped cut into parallel bedded or cross bedded. St contains of medium to coarse sand and has dark yellowish orange color. From the profile, it can infer that St predominated in this area. Sl facies are cross lamination sand. This facies found as a bed and a thin lamination layers. Generally, Sl has medium to coarse sand. Even though the grain size is quite similar to St. Sl has very pale orange color. It can define Sl as a cross lamination layer. The shape of lamination line which present in profiles is clearly uniform as a low angle. This facies can represent the paleo environment of braided river and overbank flow. The last facie is Sh. Sh has a parallel lamination in a horizontal way. Sh layers which found in the profile mostly thick than 10 cm. Sh is silty sand and has very pale orange. Sh depositional environment is generally attribute to upper flow-regime and deposit upon a point bar. Lithofacies in the area can represent the paleo-environment of paleo-channel found in braided river and a point bar.

Table 6 Summaries of lithofacies types

Facies Code/Symbol	Lithofacies	Sedimentary Structure	Texture and Colour
St	Trough cross-beded and wedge- shaped sand	Fining upward, wedge shape incistion	- medium to coarse sand - yellowish orange color
Sl	Cross-laminated sand	Trough and tubular cross-lamination, forest dip angle less than 30°	- medium to coarse sand - very pale orange color
Sh	Horizontally-beded sand	Flat beded, parallel structure thick than 10 cm	- silty sand - very pale orange

First profile is bank profile from the bank which is opposite to the GPR site no.1. (figure58) The profile is 5 m depth and 15 m long. The profile showed apparently trough and wedge-shaped cross bedded sands. Here is using blue line as a boundary divide bank profile to 2 layers for understandable explanation. The first layers, there is 2 small channels. This can interpret from the concave-up shape. The layer which is overlie on the concave-up shape, it is considered as channel fills. Alluvium that came with the current afterward can deposit into the channel and fills up. Layers that are underneath channels are side bar deposit. Also, at the first layer, it found unit bars. The structure for unit bars has a high-angle clinoform and all parallel in one layers. At the second layers, there is the wedge-shape which can define as a channel. It is about 6 m long and about 1 m thick. Since the shape of the channel is quite big, it can determine as a secondary channel scours and fills. Also, at the underneath of the channel, there is side bar deposit which is bigger than its presents in the first layer.

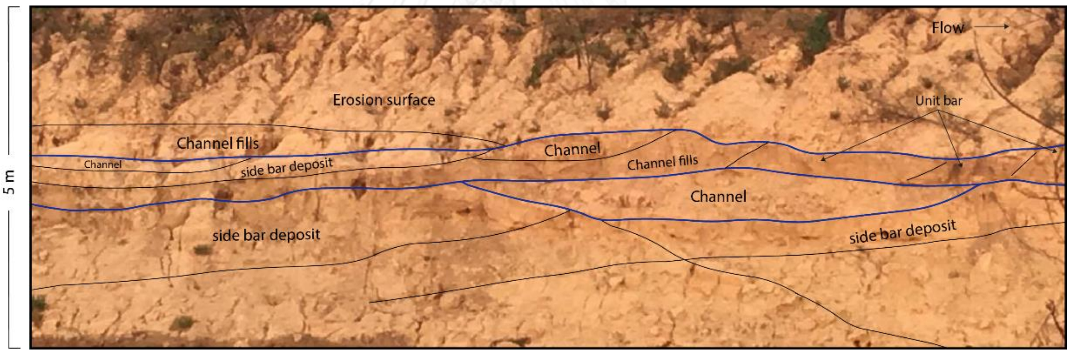


Figure 58 Collected bank profile from Mun River showed trough and wedge-shaped cross bedded sands facies (St). (Bank location showed in figure16.)

The line 7's profile was collected from the site no.2 at 20 m of GPR survey line. (Figure54) Because it is a minor scale profile (not more than 1 m depth), it cannot see the profile structure in GPR signal. The top of the profile is a top soil layer and has thickness about 30 cm. As it can see in the figure59, a top soil layer has erosion traces and soil can identify as A to B soil. After the top soil, it found quite a thick parallel lamination layer about 10 cm. This layers can be a sand lamination to thick bed. At 40 – 62 cm, it predominated by Sl facies and present shape of cross lamination. About 61 – 62 cm, it supposedly see a thin bed of cross lamination. The direction of all cross lamination is the same dipping to north-ease. From 62 – 80 cm, it predominated by St facies. The sand layers showed apparently trough and wedge-shaped cross bedded. From 80 cm, it can identify as Sh facies which can be a sand lamination to thick bed.

The line 8a's profile was collected from the site no.2 at 45 m of GPR survey line. (Figure56) The profile is 100 cm depth. Top soil is about 20 cm. There present tree root and erosion traces. St facies predominated 20 – 50 cm and 73 – 90 cm. All the St facies layers are interfering by Sh facies and can see clearly parallel strip. Sl facies also presents in this profile. It predominate in the middle part of profile from 40 – 73 cm and represent characteristic of cross and inclined lamination. About 60 – 61 cm, it supposedly see a thin bed of cross lamination. Moreover at 60 cm, it found iron concretions which are hard and compact mass of matter formed by oxidation of iron and sediments.

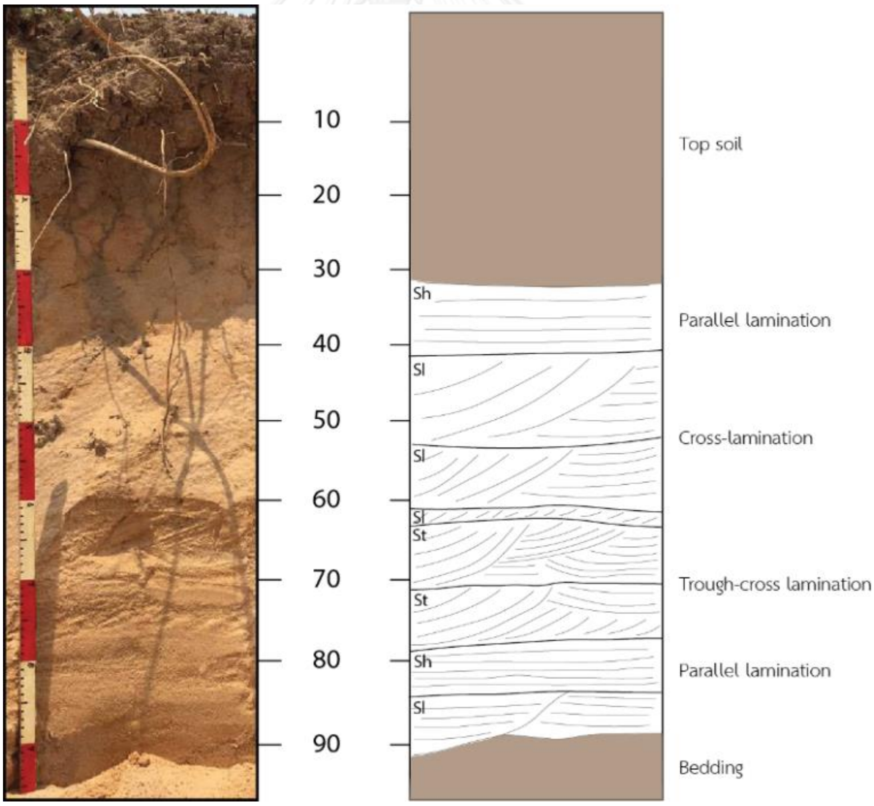


Figure 59 Profile from GPR line no.7 at m site no 2. (Location showed in figure16)

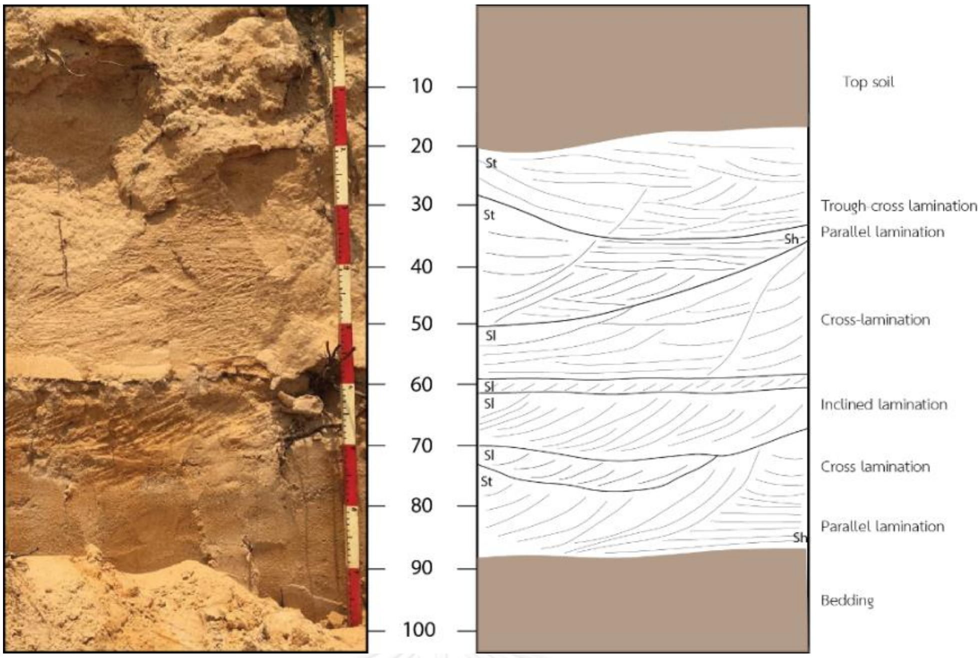


Figure 60 Profile from GPR line no.8a at m site no 2. (Location showed in figure16)

Chapter 5
Discussion

The study of fluvial geomorphology change of Mun River in western part of Changwat Buriram has been carried out by aerial photo and satellite image interpretation, geomorphic criteria calculation, profiling and ground penetrating radar survey. The results grant proficiency information about geomorphology change in term of quantity information (geomorphic criteria) and quantitative information (shape of geomorphology), radar facies and subsurface structure. From those results, there are 3 interesting main points which attract for this research discussion. Firstly, it is about the trend form geomorphic criteria values and the question about their relationship effecting to fluvial geomorphology. Secondly, the data from GPR interpretation acquired the sub-aerial structures offer interesting features of subsurface internal structure of point bar. These data can lead to comprehension of point bar formation. Finally, the available data from the area survey and results from radar facies can help to summarize the unique characteristic of source of sediment in Mun River.

5.1 Change of Geomorphic Criteria

The change of geomorphic criteria can reflect changes of channel geometry and their behavior (William, 1984). Among channel width (W), sinuosity index (SI) and radius of curvature (RC), their variations can be related to each other because of their coordinate factors. In this research, there is the contrast between those 3 geomorphic criteria. Within 30 years, SI was increased but RC/W and W showed that the channel has low erosion rate and narrower. Lewin (1976) suggested that low erosion rate and river become narrower were an effect from the mid-channel bar development. When the mid-channel bar attached alternately to one bank, bar increases in height, length and migrates to downstream and after that the alternate bank emerges. also suggested that after the new bank emerged, sediment is deposited on the inner bank of the developed bend. The development of mid-channel bar can cause deposition effect more than erosion. From this reason, a channel becomes narrower and flow velocity increases. The increasing of flow velocity can cause more erosion on concave bank (Pyrce and Ashmore, 2005). It can be assumed that the erosion of the outside bend make channel length increases. As a consequence, channel become more sinuous and meandering planform developed.

The increasing of flow velocity can cause river narrower is interesting in this case. Li et al. (2007) suggested that the construction at the upstream can cause change in channel and increasing flow velocity. Juracek (1999) also stated that velocity and erosive power increase as the water flows over the dam. In Mun River, there are several checked dams along the stream for the reason of irrigation and agriculture. About 10 km upstream form the study area, there is a weir call “Ban-Kae-Wa” established in 1990 (Figure61) Therefore, the period of a weir construction was taken into consideration in this discussion. The flow velocity was calculated from the formula below (Leopold and Dunne, 1978).

$$v = \frac{Q}{A}$$

V is flow velocity (m/s). Q is flow rate (m^3/s) which is average form each year at M6A water station (downstream station). A is flow area which using the 2016 cross section from Bureau of Water Management and Hydrology, Royal Irrigation Department Thailand. The result was separated into 2 periods, before (1976 - 1989) and after (1991 – 2015) a weir construction. As a consequence, the flow velocity during the first period before a weir established tend to decreases (figure 63) but the second period it increases (figure 64). Hence, the increasing of flow velocity can be one of the reason that makes channel width of Mun River in the study decreases.

Figure 61 Ban-kae-wa weir (Photograph form Royal Irrigation Department).

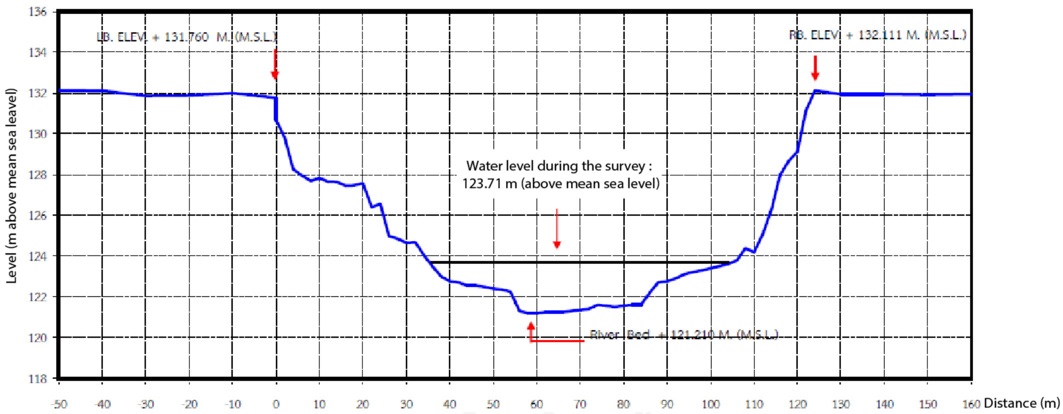


Figure 62 Channel cross-section from M6A water station 2016 (Cross section survey by Bureau of Water Management and Hydrology, Royal Irrigation Department Thailand).

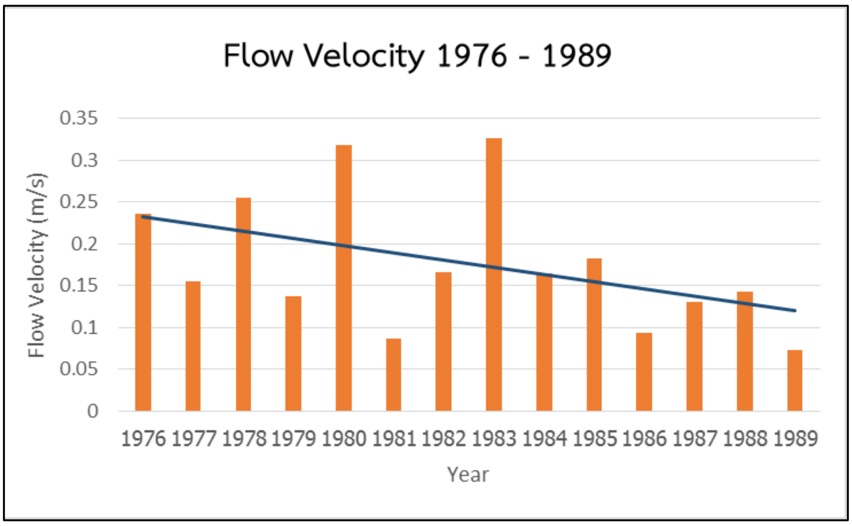


Figure 63 The graph shows flow velocity trend form 1976 – 1989.

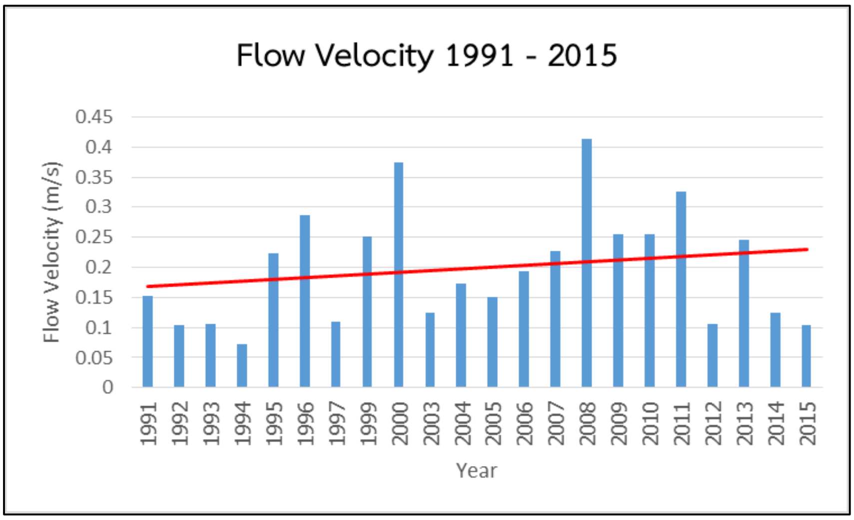


Figure 64 The graph shows flow velocity trend form 1991 – 2015.

One more reason that considers to make the channel narrower within 30 years is the discharge. Form aerial photos and satellite images interpretation, those photos and images was taken during the different seasons. Also, the digitized process before the criteria measurement has done by using the riparian edge to define the channel boundary. Therefore, the water level in the channel may cause the width variation. According to table 2, the data of discharge during the period that photos and images achieved presents in table 7.

Table 7 Discharge data of period that aerial photos and satellite images achieved (Data from M6A station, Bureau of Water Management and Hydrology, Royal Irrigation Department Thailand).

Year	Date	Discharge of Month (MCM: Million Cubic Meters)	Average Discharge of the Year (MCM: Million Cubic Meters)
1976	17th November	1,241	272.27
2006	21st January	0	224.17
2009	24th December	58.26	294.25

*Noted: In 2009, the main channel was digitized by using only ortho-image.

From table 7, 1976 is a year that Mun River has received the highest discharge comparing to the other years. Moreover, November has highest discharge of 1976.

Water overflow on floodplain. So that, bank which was processed to use in channel boundary delineation may be wider than usual. In 2006, discharge shows 0 MCM because of the drought. M6A station recorded 0 MCM from January until March. Furthermore, annual report from Department of Disaster Prevention and Mitigation of Thailand defines that Buriram area was undergone severe droughts. Comparing discharge between 2006 and 2009, 2009 has more discharge, thus, it can cause channel width (W) is wider. However, W from 2006 and 2009 did not provide big difference comparing to 1976. Additionally, the locations that provided big difference of channel width were located at the concave bends. For instance, spot no.5, 8, 13, 18, 24, 25 and 27, all of them was measured at concave or bend apex and W has changed to more than 50 m. It is common that the erosion was affected at the outside bend and bend apex more than elsewhere Hickin and Nanson (1975). Flow velocity that increases in 30 years period has more effect toward the outer bank. In summary, the reason that W in 1976 wider about 2 times than 2006 and 2009 may be caused by high discharge and measurement spot at outside bend.

5.2 The Subsurface Structure of Point Bars

The complexity of point bars sub-aerial structures form GPR survey is discussed here. Form aerial photos and satellite images interpretation, results show remnant from meander growth and movement. The behavior of meandering in Mun River is very interesting in term of the complexity of subsurface structure. GPR with 200 Hz antenna allows to document subsurface structure in large scale. The interpretation was performed at the top until about 5 m depth. As a result, 8 radar facies were classified. According to table 5, 2 facies including facies 5 and 6, are significant because they help to simplify the type of depositional pattern. Facies 5 presents the trough-like reflection which comes from scours and fills at the bar-top hollows and channel (Horn et al., 2012). The sandy channel fill facies is different depending on their depositional patterns, a braided, a meandering and a transition. The channel fill with the trough-shaped was found only in a braided pattern and the reflection mimics to the channel base (Vandenberghe and Overmeeren, 1999). Also facies 6, the secondary channel scours and fills represent a primary channel in the small system on a braided (Bridge et al., 1998). Besides, GPR form 8 survey lines have mostly reflection-liked irregularly intersection, curved up reflection with diffractions or wavy and horizontal reflection which all mean to a braided depositional pattern. In conclusion, all three facies can imply that point bars from the study area in Mun River have a subsurface structure dominated by a braided depositional pattern.

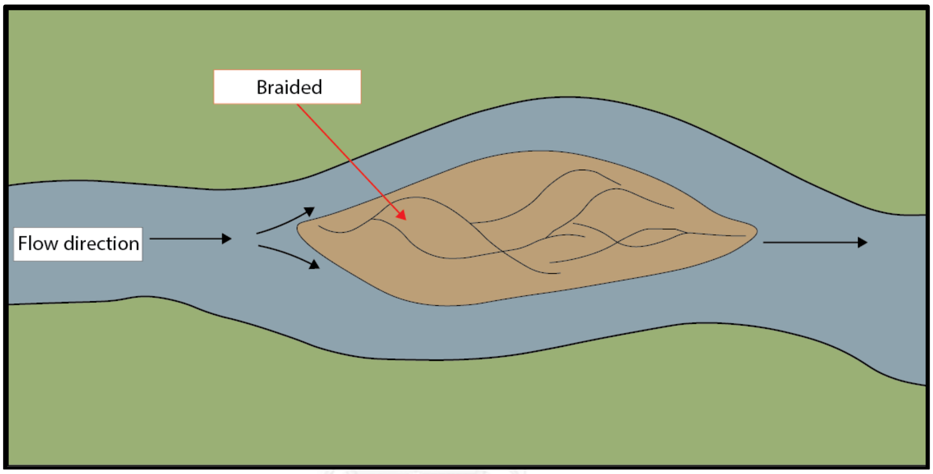


Figure 65 Mid-Channel Bar (Modified from Bridge and Lunt, 2005).

Results of geomorphic criteria calculation and a depositional pattern from GPR can indicate the unique geomorphology which related to point bars formation. Generally, channels in meandering river migrate the translation or lateral toward downstream (Fryirs and Brierley, 2012). The lateral migration maintains channel to be equilibrium form erosion at the outer bend (Leopold and Wolman, 1960). Mid-channel bar is also one of geomorphology emerges from the lateral migration and appears during the low flow season (Jiongxin, 1997). A bar separates from floodplain with free migration term (Hooke, 2013). As a result form geomorphic calculation, the channel width decreases can cause from mid-channel bar development. It was a stage during one alternate bank when it was trying to connect to one bank of a main channel. A mid-channel bar eventually became a point bar (Lewin, 1976). Ackers (1982) suggested from his experiment that it is a braided planform on the mid channel bar. A bar has quite a high elevation than the surround area but still stands in the middle of the channel like an island (Figure 65). When the discharge flow over the bar like sheet-flood, it can create the multiple channels. Thus, the signal from GPR shows as concave-upward and hummocky/wavy reflection (Skelly et al., 2003; Vandenberghe and Overmeeren, 1999).

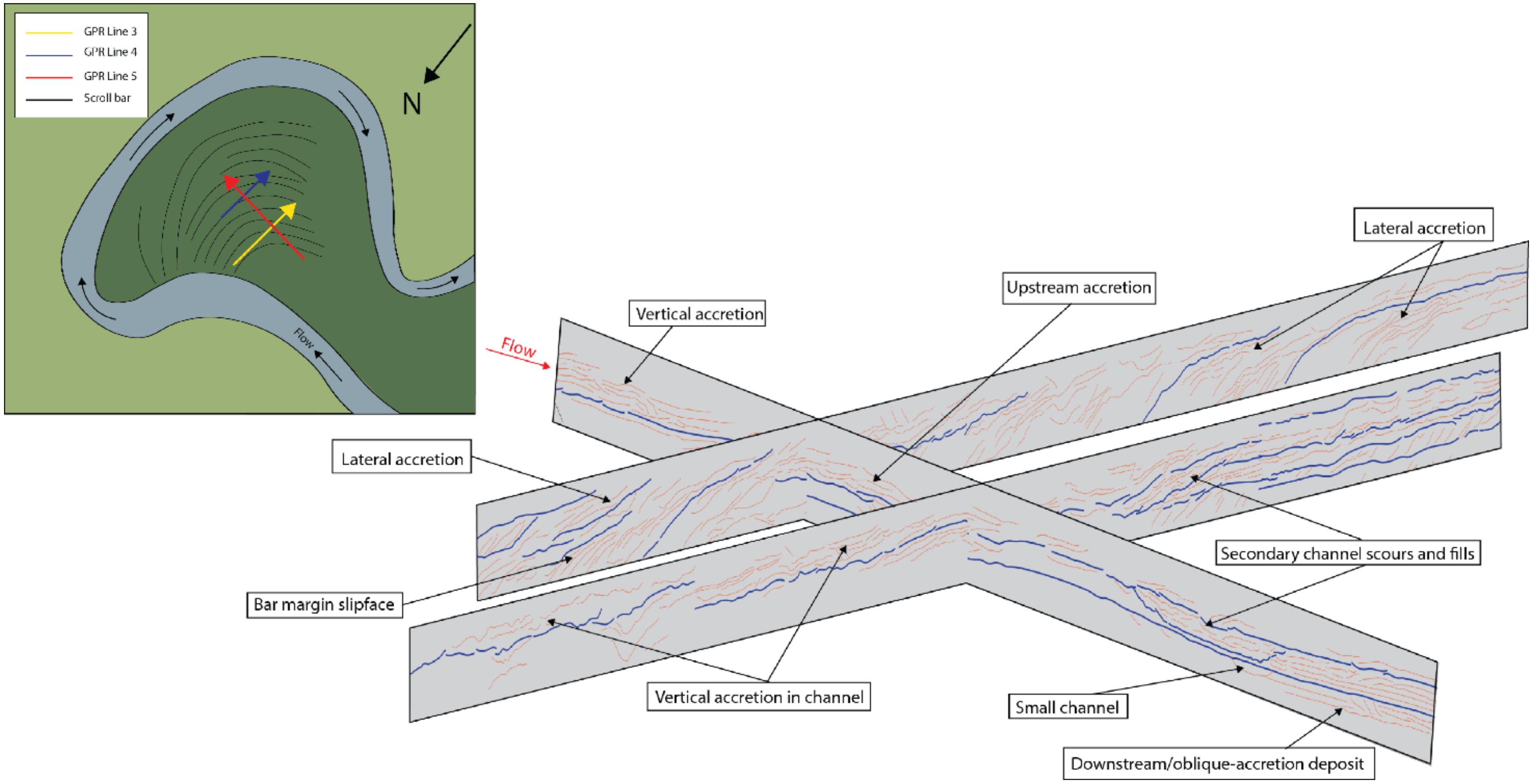


Figure 66 Fence Diagram of Point Bar Site no. 1 from GPR survey line 3, 4 and 5.

According to figure 66, a fence diagram was acquired from combining GPR line 3, 4 and 5 to indicate the subsurface profile. Below 2 m, the diagram shows explicitly the structure of a braided deposit. The multiple channels leave traces as small channels and secondary channel scours and fills both vertical and horizontal way. It is noticed that the channel traces in horizontal way is bigger because they are parallel with the main channel flow direction. From the bar mouth, the pattern of vertical accretion can be observed. The accretion in vertical way expresses in a GPR image as hummocky/wavy reflection, but it did not long and dip to one direction. Actually, vertical accretion can form in any upper base like mound or braided bar (Bridge, 2003). The vertical accretion which from the bar top can migrate laterally pass to upstream and lateral accretion deposit. Also, bar-margin slip-face and vertical accretion in channel can migrate laterally through downstream/oblique- accretion deposits. As braided bars grew up by both lateral and downstream, a lateral accretion deposit will be also a downstream-accretion deposit (Bridge et al., 1998). GPR reflection of lateral accretion shows as a curved down pattern like shingled which tend to go in downstream direction. Furthermore, there is group of GPR reflection that indicate characteristic of swale in line 3. The character of swale that shows by GPR looks likely the group of short-wavy at nearly of bar top but cannot uniform as a group of wavy toward a channel as side bar or dominates by a bigger structure like facies no. 6. At 90 -175 m (figure 40 and 41), the characteristic of swale appears from about 1 – 2 m depth.

Both surface and subsurface point bars showing that the top layer of point bar in Mun River is dominated by sand dune. Generally, the accretion on a braided bar always anastomoses to migration of lobate unit bars. The bar grew up higher several times. The bed of bar was covered by dunes while in high flow stages (Bridge et al., 1998). This can be simplified by using a model of point dune by Hickin (1969). He explained that the dunes were destructed by disequilibrium condition at an outer channel. Flow can flow through the inner part and incises the planform (Figure67D). Also, sediments can supply on the dune and cover the braided structure underneath. The effect from the incision can leave explicitly remnants such as small channels and scroll bars like it can see on both site no.1 and 2 (Figure 68 and 69). The shape of all traces mimics the shape of an outer channel. From figure 67E, the dune on a point bar is developed by lateral migration and extending their shape. The increasing of a point bar elevation makes discharge cannot flow through surface anymore. Eventually, discharge must flow around the curve. On the other hand, scroll bar at recently location was developed by the influence of the channel current and lateral migration. Scroll bar was normally developed by the erosion of the concave bank and accretion of the convex bank for maintaining channel width equilibrium (Nanson and Hickin, 1983). However, the structure of a dune is not document by GPR survey in detail. Because a dune formed at the shallow only 0.5 – 1 m depth. By the time that scroll bars are growing, point bars are transformed. According to mode of transformation, site no.1 was transformed by expansion and site no.2 was transformed by expansion and rotation (Brice, 1974; Daniel, 1971; Ghinassi et al., 2014; Jackson, 1976b). By monitoring meander scars and the set of scroll bars in the area, many point bars are transformed by expansion and rotation. The results form lines 6 and 7, indicated that expansion and rotation mode has high lateral migration toward downstream. The GPR facies that mostly found are facies 2 and 3 (Table 5).

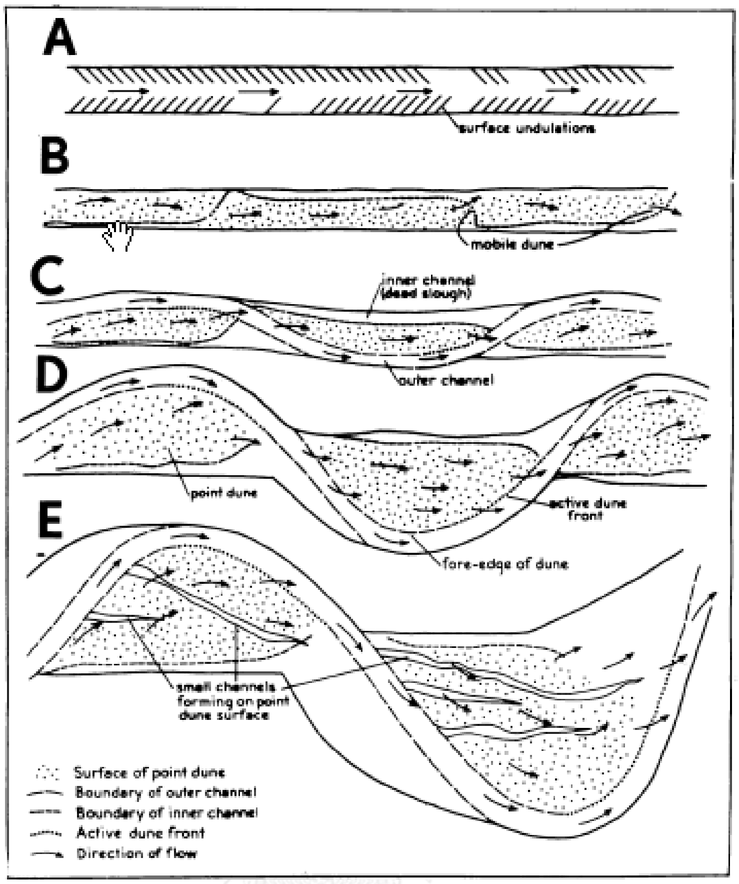


Figure 67. Model from flume experiment demonstrated stages of point dune d-evelopment (Hickin, 1969)

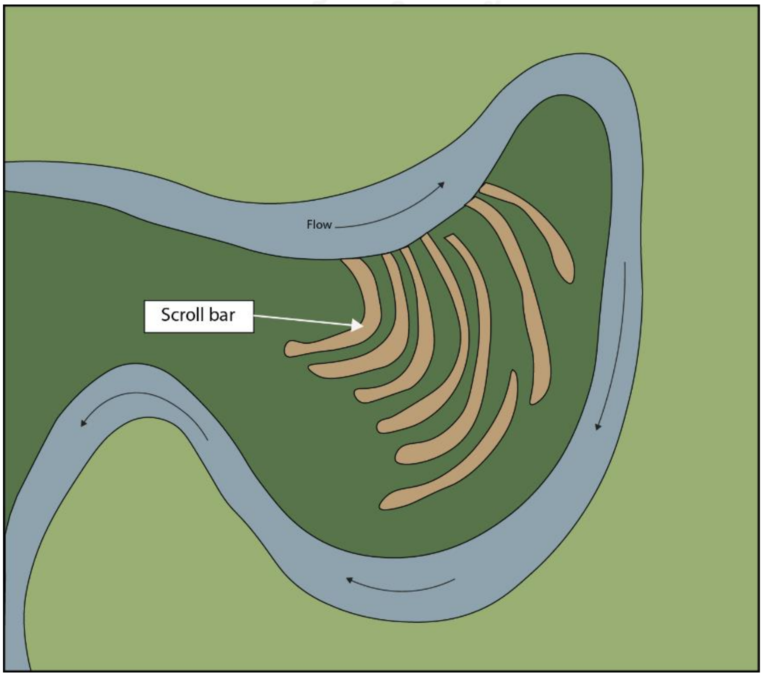


Figure 68 Scroll bar at site no.1**.**

Figure 69 Scroll bar and small channel at site no. 2.

Chapter 6
Conclusion

6.1 Conclusion

The study of fluvial geomorphology change during 30 years (1976, 2006 and 2009) of Mun River in Western Part of Changwat Buriram was carried out using the result from the analysis in geomorphic criteria and Ground Penetrating Radar (GPR). This research can be concluded as follows.

Geomorphic criteria were concluded from the results of aerial photographs and satellite images interpretation in year 1976, 2006 and 2009. The main geomorphic criteria in this study are channel width (W), sinuosity index (SI) and radius of curvature (RC). Firstly, Sinuosity Index (SI) increased from 1.5 in 1976 to 1.8 in 2006. SI remains steady as 1.8 in 2009. This indicated that the Mun River has changed its course from meander to highly class during 30 years. From SI result, it can be implied that the channel becomes more meander.

Next, result from calculating channel width (W) shows that the main channel width is decreased. In 1976, an average of W was 72.05 m. The average of channel width is literally dropped to 33.34 m and 40.28 m in 2006 and 2009, respectively. It found that W has the most changing part at the outer bank. The change is caused by the increasing of flow velocity. However, the different aerial photos and satellite images recorded time is also considered because the digitized for a channel delineation was done along riparian. Photos from 1976 were taken during bank-full period but images from 2006 and 2009 recorded when river was in drought period. This reason may cause a bit error in channel width measurement.

The last geomorphic criterion is Radius of curvature (RC). RC result shows that the river become more stability and Rc/W shows that the river is in a low erosion rate. In conclusion, geomorphic criteria calculation shows that during this 30 years the river has highly meander, narrower and low erosion.

Form field study, the total 8 subsurface GPR profiles were achieved The survey has done in 2 point bars. Both study sites present characteristics of braided subsurface structure. According to GPR interpretation, it can be elucidated GPR facies into 8 types which are hummocky/wavy, shingled, sigmoid, concave-up, isolated trough shape, isolated concaved-up, parallel and parabolic. Each type refers to different structure. The results from GPR interpretation indicated that both point bars were developed form mid-channel bars. The braided structure which appeared in GPR image is from multiple channels on a bar. Furthermore, the traces from surface point that the mid-channel bars were covered by dune. In short, GPR shows that both point bars have developed from mid-channel.

The last part of the study is the result from stratigraphic profiles interpretation. There are 3 lithofacies found in this area including St, Sl and Sh. All of them are members of sandy group lithofacies. It is noticed that these sands were eroded from Mahasarakham Formation basement and then provided Quaternary sediments that were distributed cover the area of Mun River.

6.2Recommendation

6.2.1 GPR shows as excellent tool for detecting subsurface sedimentary structure in particular sand sediments. This research applied 200 MHz of GPR antenna to which they can be scanned at a limited depth (5 m in average). Using more variety of GPR antenna surveys is recommended in order to collect more data in detail of deeper part and perhaps in a shallow depth as well.

6.2.2 This research applied only 30 years time span to analyze geomorphic changes of the river. However, even some changes can be detected, but the longer period of analysis would be appropriated.

6.3.3 Some exposures, e.g., road-cut outcrops, river bank erosion profiles can be additionally studied in the future in order to compare the GPR facies with stratigraphy or internal sedimentary structures within point bar sand. This research is successful to proof that GPR can be applied for studying detail point bar depositional features.

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APPENDIX

APPENDIX A

Field Study

Figure 70 GPR Survey line 8 site no.2 (road-cut outcrops)

Figure 71 Road-cut outcrops form site no.2 on a point bar of Mun River western part of Changwat Buriram, Thailand.

Figure 72 Bank profile location. This bank located opposite the GPR survey site no.1 in Mun River western part of Changwat Buriram, Thailand. From the top to the water level, the bank high is about 5 m.

APPENDIX B

Secondary Data

Runoff data is used to calculate trend of flow velocity in Mun River during 1976-2009. The data was documented from M6A water station, Bureau of Water Management and Hydrology, Royal Irrigation Department Thailand. This station located upstream from the study area and Ban-kae-wa weir. Moreover, runoff data was shown the quantity of discharge from each month. The recorded of monthly discharge can use to identify the state of Mun River during the period that aerial photos or satellite image was taken.

Table 8 Monthly Discharge of M6A water station, Bureau of Water Management and Hydrology, Royal Irrigation Department Thailand.

Year	Monthly Discharge (MCM: Million Cubic Meters)												Average flow
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	rate (m^3/s)
1976	1.95	8.52	4.00	2.53	13.20	384.65	1,174.34	1,241.05	372.73	40.47	14.15	9.62	103.60
1977	4.92	5.95	4.78	4.53	77.22	1,073.34	777.85	124.67	45.87	19.52	7.32	4.89	68.20
1978	3.05	5.65	18.23	416.65	372.32	1,015.89	2,247.18	319.73	58.76	24.81	11.47	9.93	142.81
1979	1.95	58.59	313.89	260.87	56.21	43.07	351.68	32.87	11.24	3.21	0.54	0.65	35.89
1980	4.10	5.85	85.17	309.77	99.34	783.56	1,812.98	948.01	296.65	43.38	17.47	12.37	140.11
1981	8.27	11.95	53.36	247.64	339.46	87.60	52.11	60.81	84.99	19.33	7.54	4.25	30.99
1982	0.60	0.61	1.12	1.45	40.05	1,708.59	902.07	203.30	66.65	11.32	2.98	1.88	93.25
1983	1.06	3.34	9.46	52.31	426.95	607.72	2,399.80	1,733.70	470.21	58.29	20.22	6.69	183.09
1984	6.21	7.75	156.44	156.61	69.20	289.53	369.72	213.79	58.42	16.12	4.74	1.48	42.81
1985	1.41	57.51	73.27	70.98	133.49	313.29	707.32	508.65	178.84	22.52	3.65	0.84	65.70
1986	7.14	10.95	11.58	6.65	157.34	372.86	180.14	235.17	57.51	16.56	4.44	2.36	33.70
1987	2.60	1.97	6.65	3.35	1.70	311.17	685.38	257.16	181.18	23.52	5.42	2.86	46.90
1988	3.98	38.84	153.49	83.42	86.96	62.17	349.40	615.51	195.16	26.60	4.42	1.80	51.43
1989	1.03	1.81	1.98	38.14	23.85	93.01	61.73	144.02	40.00	7.00	1.81	3.42	13.25
1990	0.77	1.14	0.79	2.41	247.83	246.44	445.88	758.22	291.59	34.92	7.18	3.17	64.70
1991	0.70	0.37	2.96	7.19	15.82	315.04	1,214.08	507.28	44.51	12.60	3.65	3.65	67.29
1992	1.08	0.33	2.52	1.94	40.31	184.97	164.38	133.30	47.05	5.63	2.64	1.45	18.57
1993	1.27	1.08	6.22	122.26	60.13	198.93	145.45	52.06	6.99	2.44	0.47	0.00	18.94
1994	0.00	1.30	16.88	144.92	16.34	286.36	323.23	23.55	3.59	1.11	0.00	0.00	25.92
1995	0.00	0.00	0.00	109.92	340.04	590.05	1,379.80	581.05	86.16	13.88	4.26	4.20	98.33

VITA

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