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PHYSICAL PROPERTIES AND STRUCTURES OF RIVER BANK SEDIMENTS IN BANG BAN CANAL, AMPHOE BANG BAN, CHANGWAT PHRA NAKHON SI AYUTTHAYA

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Field of Study	Geology
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Submitted date..............................

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คลองบางบาลเป็นคลองสาขาแยกมาจากแม่น้ำเจ้าพระยา มีความยาวประมาณ 16 กิโลเมตร พบการพังทลายของตลิ่งแม่น้ำในช่วงเวลาที่น้ำลดระดับลงมาก งานวิจัยนี้จึงศึกษาถึงโครงสร้างตะกอนตลิ่งแม่น้ำบริเวณคลองบางบาล เพื่อระบุสาเหตุเชิงธรณีวิทยาของการเกิดการพังทลายของตลิ่ง โดยได้ทำการสำรวจพื้นที่และทำการเจาะเพื่อเก็บตัวอย่างดินนำมาวิเคราะห์เป็นจำนวน 4 หลุม ได้แก่ BC1 BC2 BC3 และ BC4 จากการหาขนาดมวลคละของดินพบว่า ในทุกหลุมที่เจาะสำรวจตั้งแต่ผิวดินไปจนถึงความลึกประมาณ 3 เมตร องค์ประกอบหลักของชั้นดินจะเป็นทรายแป้งและดินเหนียว และตั้งแต่ความลึก 3 เมตรเป็นต้นไปองค์ประกอบจะเปลี่ยนเป็นทรายละเอียดมากถึงทรายละเอียด แสดงให้เห็นว่าด้านบนของตลิ่งคลองบางบาลเป็นดินเชื่อมแน่น (cohesive soil) ในขณะที่ส่วนล่าง (3 เมตรลงไป) เป็นดินที่ไม่มีความเชื่อมแน่น (cohesionless soil) ในส่วนของการศึกษาโครงสร้างของตลิ่งบริเวณวัดบางบาลด้วยจีพีอาร์ ซึ่งเป็นจุดศึกษาที่มีการเจาะหลุม BC2 BC3 และ BC4 สามารถแปลความได้ว่า ส่วนล่างของตลิ่งที่ความลึก 3 เมตรเป็นต้นไป มีการแสดงลักษณะการงอกของสันดอนทรายโบราณ และมีลักษณะของตลิ่งโบราณ จึงคาดว่าคลองบางบาลเคยเป็นลำน้ำโค้งตวัดมาก่อน ส่วนด้านบนถูกปิดทับด้วยคันดินธรรมชาติที่เกิดขึ้นภายหลังและปิดทับส่วนของทางน้ำโบราณ และมีความสอดคล้องกับการแปลภาพถ่ายดาวเทียมด้วย

ลักษณะของตลิ่งในพื้นที่ศึกษาเป็นรูปแบบตลิ่งแบบผสม โดยตลิ่งด้านบนเป็นดินที่มีความเชื่อมแน่นซึ่งทนต่อการกัดเซาะได้ดีกว่าตลิ่งด้านล่าง นั่นคือหากระดับน้ำในคลองลดลงถึงตลิ่งส่วนล่าง อาจเกิดการกัดเซาะมากขึ้นในชั้นตลิ่งที่ไม่มีความเชื่อมแน่น และเกิดเป็นตลิ่งเว้าด้านล่างง่ายต่อการพังทลายของตลิ่ง และจากดัชนีการกัดเซาะของตลิ่ง (BEHI) สรุปได้ว่าตลิ่งบริเวณวัดบางบาลมีความเสี่ยงต่อการถูกกัดเซาะในระดับสูงมาก

ภาควิชา ธรณีวิทยา ลายมือชื่อนิสิต ....

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THEERACHET CHAOMEEPURM : PHYSICAL PROPERTIES AND STRUCTURES OF RIVER BANK SEDIMENTS IN BANG BAN CANAL, AMPHOE BANG BAN, CHANGWAT PHRA NAKHON SI AYUTTHAYA. ADVISOR : PROF. MONTRI CHOOWONG, Ph.D., 52 pp.

Bang Ban Canal is a stream that has a lot of river bank failure reports. To find out the geological causes of river bank failure in the area, this study focuses on physical properties and structures of river bank sediments. There are 4 boreholes of soil which are BC1, BC2, BC3, and BC4. In every borehole, mean grain size of soil changes at the depth of 3 metres approximately. Upper part of river bank mainly consists of silt and clay while lower part of river bank consists of coarser materials (fine sand to very fine sand). It can be concluded that upper part of river bank is cohesive soil while lower part of river bank is cohesionless soil. According to GPR survey, the structure of river bank in Bang Ban Canal (at Wat Bang Ban) can be classified into two parts. First, lower part of river bank is the old point bar and palaeochannel of Bang Ban Canal, therefore, it was a meandering stream. Second, upper part of river bank is natural levee which overlain lower part as unconformity. These are corresponded to aerial photograph interpretation.

Bang Ban Canal's bank type is composite bank. The upper part is cohesive soil which is more resistant than the lower part, cohesionless soil. If river level lowers to the lower part, the erosion rate will increase significantly. When the lower part is eroded, river bank failures will occur easily. According to Bank Erosion Hazard Index (BEHI), river bank at Wat Bang Ban is classified as very high risk.

Department : Geology Student's Signature ....
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1 INTRODUCTION

1.1 BACKGROUND

Bangkok and surrounded provinces, including Phra Nakhon Si Ayutthaya, are in the geological area called Central Plain of Thailand. It has many main rivers and a lot of small canal (DMR, 2007). According to its geomorphology, Central Plain residents have suffered from problems caused by rivers and canals; one of many problems that affect economy is river bank failure. River bank failure is occurred by 2 main causes which are river bank erosion and Geotechnical instabilities (Charoenrien, 2006). River bank failure tends to occur either river water level is relatively low or high than normal level, as in Bang Ban canal. Hubble and De Carli (2015) have also done research about river bank failure in southern region of Australia which happened in the time of drought.

Bang Ban canal, Amphoe Bang Ban, Changwat Phra Nakhon Si Ayutthaya is a potential area to study about river bank failure because there are roads passing there and depth and width of the canal are suitable for studying. Bang Ban canal is a canal which separates from Chao Phraya river. Moreover, in dry season, its water level is low enough which makes it easier to pick up samples. In addition, an important reason, why we should study this area, is that there are river bank failures every year. To study about stratigraphy and physical properties of river bank sediments from each stratum will be useful for predicting and analysing the causes of river bank failure in the certain area. We can predict the type of river bank failure and find an proper way to prevent it.

To prevent river bank failure, varied materials and structures will be used for different nature of river bank. Charoenrien (2006) stated that River bank preventions consist of bank protection dam, river flow divert structure, and natural prevention. Therefore, this research will contribute data about the nature of Bang Ban canal which will improve the river bank protection efficiency.

1.2 RATIONALE

1. Increase in river bank erosion both during rainy and dry seasons.
2. Decrease in stability of soil and slope.
3. Necessity of analysis in physical properties of river bank sediments.

1.3 OBJECTIVES

1. To describe stratigraphy of river bank in the area.
2. To test physical properties of sediment from each stratum.
3. To create river bank profile from GPR survey in the area.

1.4 STUDY AREA

Study area is located in Amphoe Bang Ban, Changwat Phra Nakhon Si Ayutthaya. There are several roads passing there, making it suitable area.

The length of Bang Ban canal is about 16.976 kilometres; however, study area is focused on the north part of the canal as shown in Figure 1.

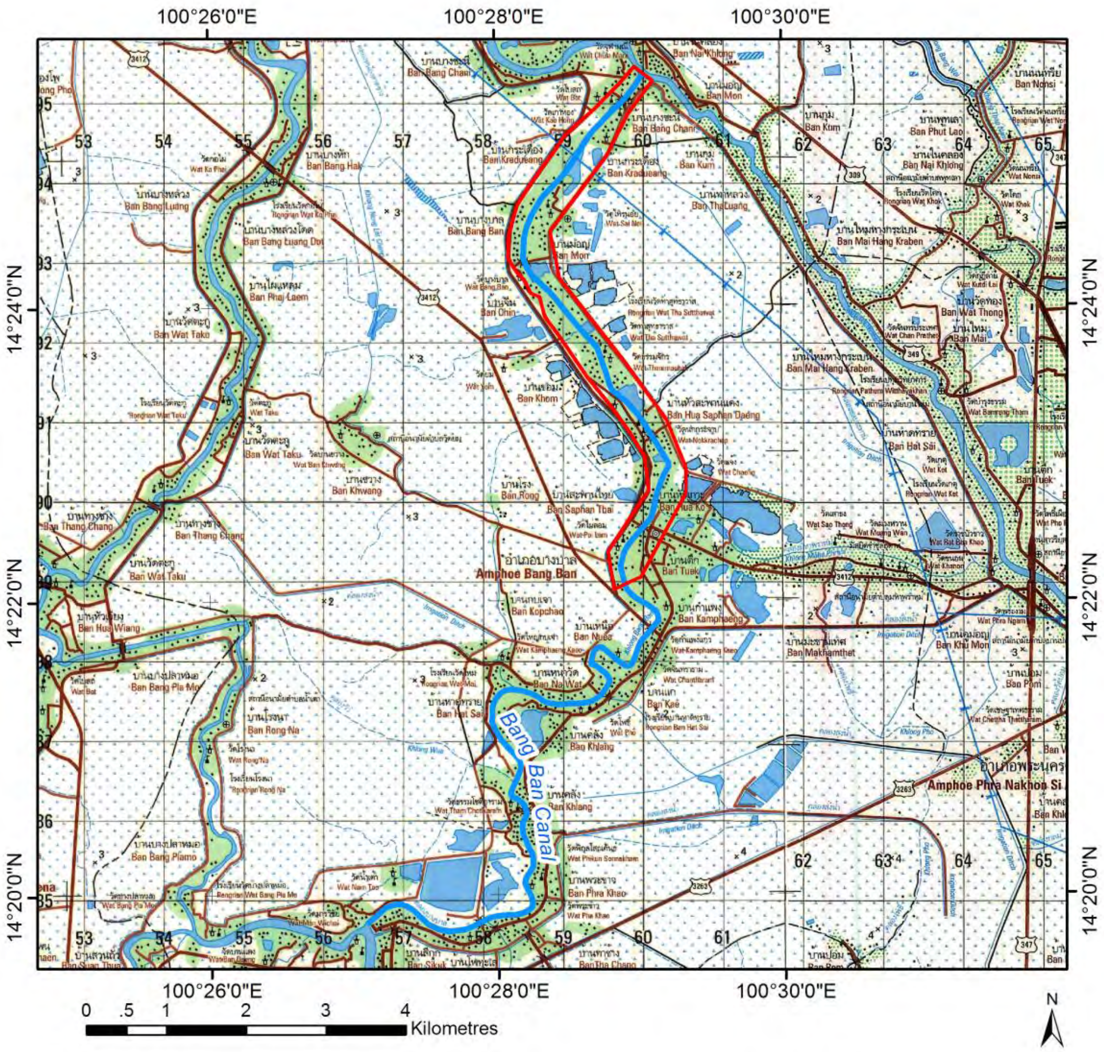


Figure 1. Study area is located within the red rectangle and Bang Ban canal is highlighted with light blue line. (Royal Thai Survey Department, 2004a/2004b)

1.5 ASSUMPTION OF THE STUDY

River banks in the study area should consist of sand, silt, and mud sediments; however, it should be mud-dominated because there are river bank failures along the canal during both dry and wet seasons. Mud-dominated river banks can fail from increase in soil pore pressures during rapid drawdown river level.

Contrary to first assumption, if river banks in the study area are sand-dominated, river bank failures should be caused by slope stability and erosion.

2 LITERATURE REVIEW

2.1 OVERVIEW

In my literature review, I have found some good research papers discussing river bank failure that happened in southern region of Australia during drought period which is similar to the situation in Bang Ban canal. Therefore, this research methodology will mainly base on a paper, Mechanisms and Processes of the Millennium Drought River Bank Failures: Lower Murray River, South Australia, by Hubble and De Carli (2015).

2.2 GEOMORPHOLOGY OF THE STUDY AREA

According to the Geomorphological survey map (H. Ohkura, S. Haruyama, M. Oya, S. Vibulsresth, R. Simkinh, R. Suwan-Werakamtorn, 1989), Bang Ban canal area, as shown in Figure 2a, is classified as lower natural levee—its description is this part gets submerged in flood time but the water drains off well.

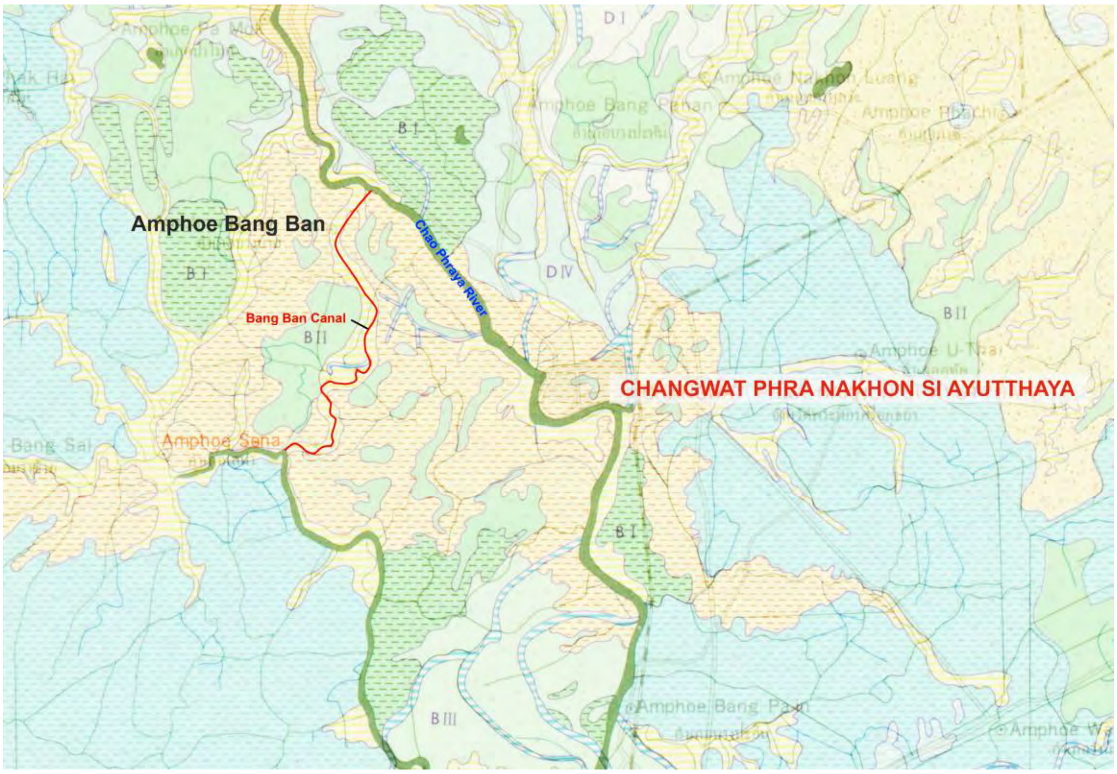


Figure 2a. Geomorphology map of the study area, edited from A Geomorphological Survey Map of the Central Plain of Thailand Showing Classification of Flood-inundated Areas (H. Ohkura et al., 1989). Bang Ban canal is illustrated as red line in this figure.

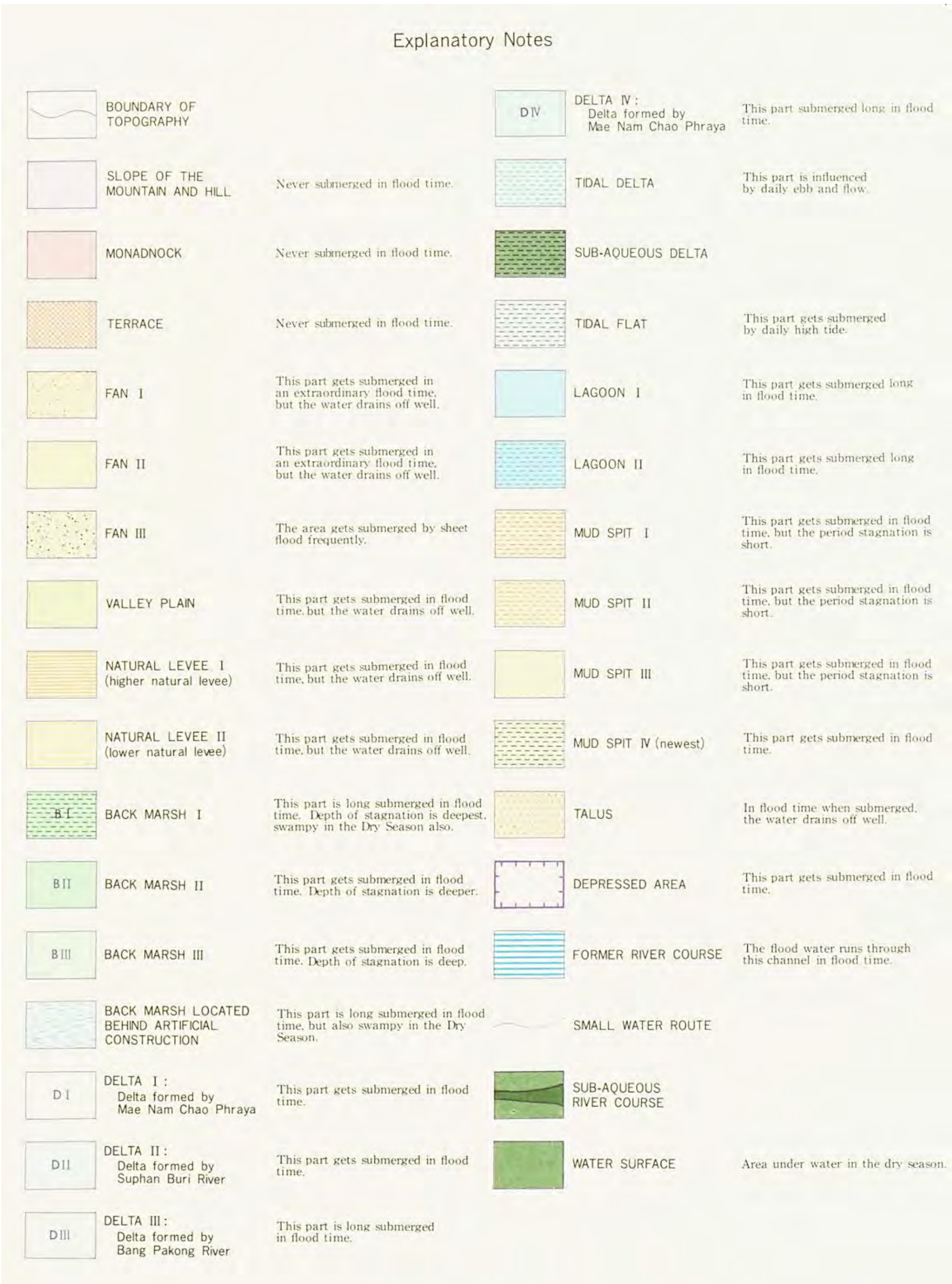


Figure 2b. Explanatory notes of Figure 1a. (H. Ohkura et al., 1989)

2.3 CAUSES OF RIVER BANK FAILURES

River bank failures are caused by seven factors which are used in the BEPI (Bank Erosion Potential Index) (Rosgen, 2001). The seven factors are bank materials, hydraulic influence of structures, maximum bank height divided by the OHWM (bankfull) height, bank slope. Stratification or bank layering, bank vegetation, and thalweg location.

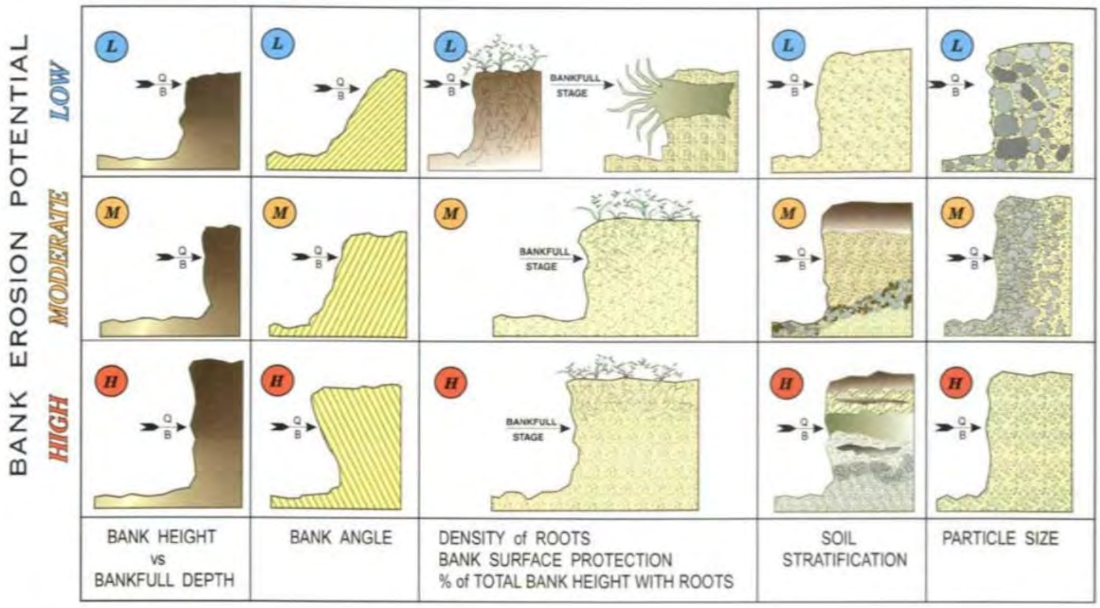


Figure 3. River bank erodibility factors. (Rosgen, 2001)

2.3.1 STREAM BANK CHARACTERISTICS

Rosgen (2001) has identified key streambank characteristics that would be sensitive to the processes of erosion to develop the BEHI rating. These streambank variables are bank height ratio (stream bank height/maximum bankfull depth), rooting depth ratio, rooting density, percentage of protected surface, bank angle, soil stratification, and bank material composition. All of them will be measured and assembled as predictors of erodibility (BEHI). They will be converted to a risk rating of 1-10 (10 being the highest level of risk). The risk ratings from 1 to 10 indicate corresponding adjective values of risk of very low, low, moderate, high, very high, and extreme potential erodibility. The detailed categories of risk are shown in Table 1.

Table 1. River bank erosion metric ranking scores for calculation of the BEHI. (Rosgen, 2001)

Category		Bank Ht. Ratio (m/m)	Root Depth Ratio (%)	Root Density (%)	Bank Angle (Degrees)	Surface Protection (%)	Total Index
Very Low	Value	1.0–1.1	100–80	100–80	0–20	100–90	
	Index	1–2	1–2	1–2	1–2	1–2	≤10
Low	Value	1.1–1.2	80–55	80–55	20–60	90–50	
	Index	2–4	2–4	2–4	2–4	2–4	10–20
Moderate	Value	1.2–1.5	55–30	55–30	60–80	50–30	
	Index	4–6	4–6	4–6	4–6	4–6	20–30
High	Value	1.5–2.0	30–15	30–15	80–90	30–15	
	Index	6–8	6–8	6–8	6–8	6–8	30–40
Very High	Value	2.0–2.8	15–5	15–5	90–120	15–5	
	Index	8–9	8–9	8–9	8–9	8–9	40–45
Extreme	Value	>2.8	<5	<5	>120	<5	
	Index	10	10	10	10	10	>45

For adjustments in points for specific nature of bank materials and stratification, the following is used:

Bank Materials: Bedrock (very low), Boulders (low), cobble (subtract 10 points unless gravel/sand>50%, then no adjustment), gravel (add 5-10 points depending on % sand), sand (add 10 points), silt/clay (no adjustment).

Stratification: Add 5-10 points depending on the number and position of layers.

2.3.2 RIVER BANK MATERIALS

River Bank failure is related to composition of the river bank material. They can be classified into four types.

Bedrock. River bank which is outcrop of bedrock is usually stable, however, it can cause erosion in the opposite river bank if it is soft material.

Cohesionless Banks. Cohesionless soils consist of silts, sands, and gravels. There is no electrical or chemical bonding between particles and are eroded particle by particle. Erosion of cohesionless soils is determined by gravitational forces, bank moisture, and characteristics of particle. Factors influencing also include seepage forces, piping, and fluctuations in shear stress.

Cohesive Banks. Clay particles are main composition in this type of river bank. Clay particles create higher level of bonding between the particles. As a result of bonding, cohesive soils are more resistant to erosion because they are less permeable. This also reduces the effects of seepage and piping. However, because of their low permeability, cohesive soils, or cohesive banks, are likely to fail during rapid drawdown of water level due to increase in soil pore water pressures.

Stratified or Interbedded Banks. These banks are the most common bank type in fluvial systems. This type of river bank consists of various materials which are different in textures, permeability and cohesion. For instance, if the river bank has a cohesive soil in upper layer and a cohesionless soil in lower layer, erosion rate is controlled by the erodibility of cohesionless layer as shown in Figure 4.

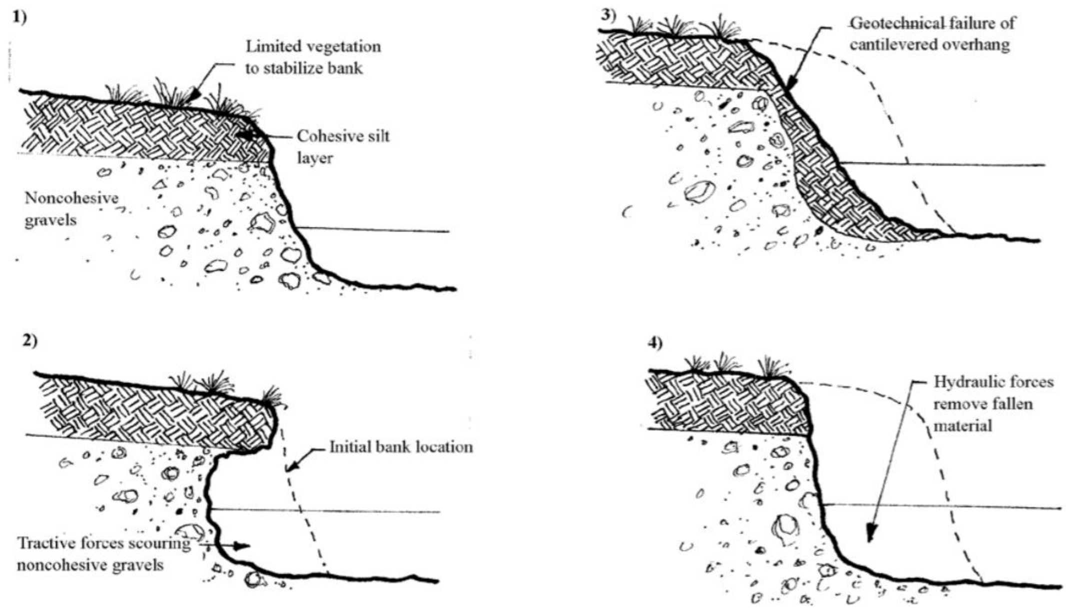


Figure 4. Stratified Streambanks and Combination Failures (Adapted from Johnson and Stypula, 1993)

2.4 RIVER BANK FAILURES IN LOWER MURRAY RIVER, AUSTRALIA

During the peak of the Millennium Drought pool levels of the Lower River Murray fell 1.8 metres below the normal operating range. This research found that the majority of the larger bank failure features are associated with deep scour holes that have been eroded into channel floor due to bedrock margin constriction, large outcrops of bedrock which lies at the floor of the channel. Those features generate erosive flow patterns during periods of higher flow that have scoured deep holes and eroded the downstream river bank and over-steepened the channel margins.

The banks located adjacent to deep scour holes are over-steepened and usually fail when water level falls. In addition, slope stability modelling shows that the river bank failures in Lower River Murray were caused by lowered river levels and the presence of Soft Clay within the bank materials.

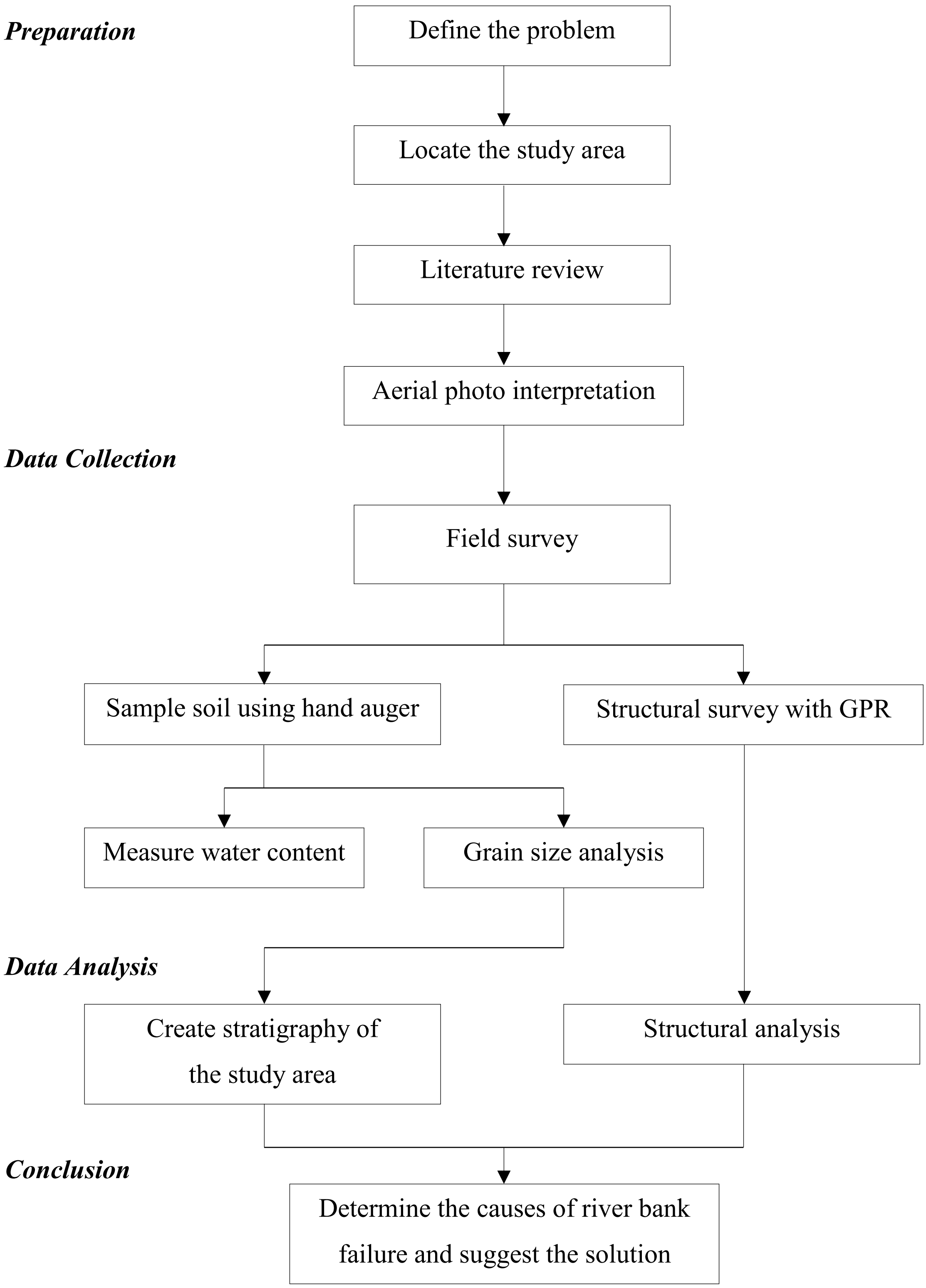
2.5 RIVER BANK FAILURES IN NIGER DELTA, NIGERIA

Most of the rivers of Niger Delta flow through alluvial deposits whose upper part of stratigraphy is cohesive silty clay while lower part is cohesionless sand. Erosion and recession of the river banks have been a threat to many villages along the delta area.

Analyses of the recessional mechanisms indicate that bank failure is initiated by much faster erosion rate of the lower cohesionless bank layer than the upper cohesive bank layer which develops the overhangs of the upper cohesive materials. This can lead to river bank failure.

3 METHODOLOGY

3.1 OVERVIEW



3.2 STUDY AREA

The factors that alter selection of study area are an easy of access, for instance, there is a road to the river bank and there is not much vegetation. River bank failures should have occurred in the study area. Another factor is that, if the study area is near to local people's assets, it would be more beneficial.

The candidate-areas are Sena and Bang Ban canal in Changwat Phra Nakhon Si-Ayutthaya. Both are natural streams which river bank failures had occurred. Since travelling to Bang Ban canal is easier, its terrain is flatter, and Bang Ban canal bank is suitable, therefore, Bang Ban canal is chosen for this research.

Figure 5. River bank failure at Wat Bang Ban, alongside Bang Ban canal.

Figure 6. River bank failure protection alongside Bang Ban canal.

3.3 FIELD SURVEY

During the field survey, we collect primary data of soil, GPR data, and river bank height profile.

3.3.1 HAND AUGER SOIL SAMPLING

The hand auger is suitable for unconsolidated formations: sand, silt and soft clay. The hand auger consists of extendable steel rods, rotated by a handle. A number of different steel augers (drill bits) can be attached at the bottom end of the drill rods. The augers are rotated into the ground until they are filled, and then lifted out of the borehole to be emptied. Above the water table, the borehole generally stays open without the need for support and can be dug easily. Under the water table, however, it is nearly impossible to sample soil.

Figure 7. Equipment and procedure (left), soil samples from hand auger (right).

3.3.2 GPR SURVEY

Ground-penetrating radar (GPR) is a geophysical method that uses radar pulses to image the subsurface. This non-destructive method uses electromagnetic radiation in the microwave band (UHF/VHF frequencies) of the radio spectrum, and detects the reflected signals from subsurface structures. (Wikipedia, 2017)

This project uses GPR frequency at 200 MHz and explores 4 lines, parallel-to-stream 1 line and perpendicular-to-stream 3 line, therefore, I can create a fence diagram.

3.3.3 RIVER BANK HEIGHT PROFILE

River bank height profile is created by measuring the height (using Total Station) of each point along the line which is perpendicular to stream line. The height profile is then created by plotting in spreadsheet programme.

Figure 8. Total station survey for creating river bank height profile

3.4 SAMPLE ANALYSES

Samples are analysed into two factors; water content and grain size analysis.

3.4.1 WATER CONTENT

Water content or moisture content is the quantity of water within material (in this research–soil). It can be defined in two main different ways which are volumetric water content and gravimetric water content. Volumetric water content is defined as

$$\theta = \frac{V_w}{V_{wet}}$$

where V_w is the volume of water and V_{wet} is equal to the total volume of the wet material including soil particles, water, and air. (Wikipedia, 2017)

This research measures water content in both two definitions in samples no. BC1 and BC2 while samples no. BC3 and BC4 is measured only volumetric water content. In this research, volumetric water content is measured by equipment called ProCheck and gravimetric water content is measured by oven drying method.

Oven Drying Method

According to Engineeringcivil.com (2017), The soil specimen should be representative of the soil mass. The quantity of the specimen taken would depend upon the gradation and the maximum size of particles.

Procedure to determine water content in soil by oven drying method

a) Clean the container, dry it and weigh it (weight 'W1').

b) Take the required quantity of the wet soil specimen in the container and weigh it (weight 'W2').

c) Place the container with soil in the oven till its weight becomes constant (normally for 24hrs).

d) When the soil has dried, remove the container from the oven.

e) Find the weight 'W3' of the container with the dry soil sample.

The water content; w = [W2-W3]/[W3 -W1]*100%. An average of three determinations should be taken.

3.4.2 GRAIN SIZE ANALYSIS

To analyse grain size of soil, we do dry sieve analysis using a sieve shaker and meshes (no. 5, 10, 18, 35, 60, 120, 230, and pan). After we get particle size distribution data, they will be calculated using moment of method. The mean value is used for classification of grain size in Table 2.

Table 2. Wentworth Size Classification (Wentworth, 1992)

	Mean grain size : Mean	
Phi (f)	Grain size (mm)	Wentworth size class
-1 - 0	1.00 – 2.00	Very coarse sand
0 – 1	0.50 – 1.00	Coarse sand
1 – 2	0.25 – 0.50	Medium sand
2 – 3	0.125 – 0.25	Fine sand
3 - 4	0.0625 – 0.125	Very fine sand

3.4.3 SOIL CLASSIFICATION

This project uses dry sieve method to find grain size distribution, therefore, we cannot find the proportion of silt and clay separately. However, we will use USCS in simply way as described in Table 3. Then add sized-name using mean grain size.

Table 3. Soil classification (modified from USCS)

Criteria for assigning soil group		
Coarse-grained soils More than 50% of retained on No. 200 sieve	**Gravels** More than 50% of coarse fraction retained on No. 4 sieve	**Clean gravels** Less than 12% fines **Gravels with fines** More than 12% fines
	Sands 50% or more of coarse fraction passes No. 4 sieve	**Clean sands** Less than 12% fines **Sands with fines** More than 12% fines
Fine-grained soils 50% or more passes No. 200 sieve	**Silts and clays**	

4 RESULTS

4.1 AERIAL PHOTOGRAPH INTERPRETATION

There are a lot of sand pits in the study area. Estimated 250 metres from Bang Ban Canal, vegetation density is higher than the surrounding area, therefore, it can be interpreted as natural levee. Aerial photograph interpretation is shown in Figure 9.

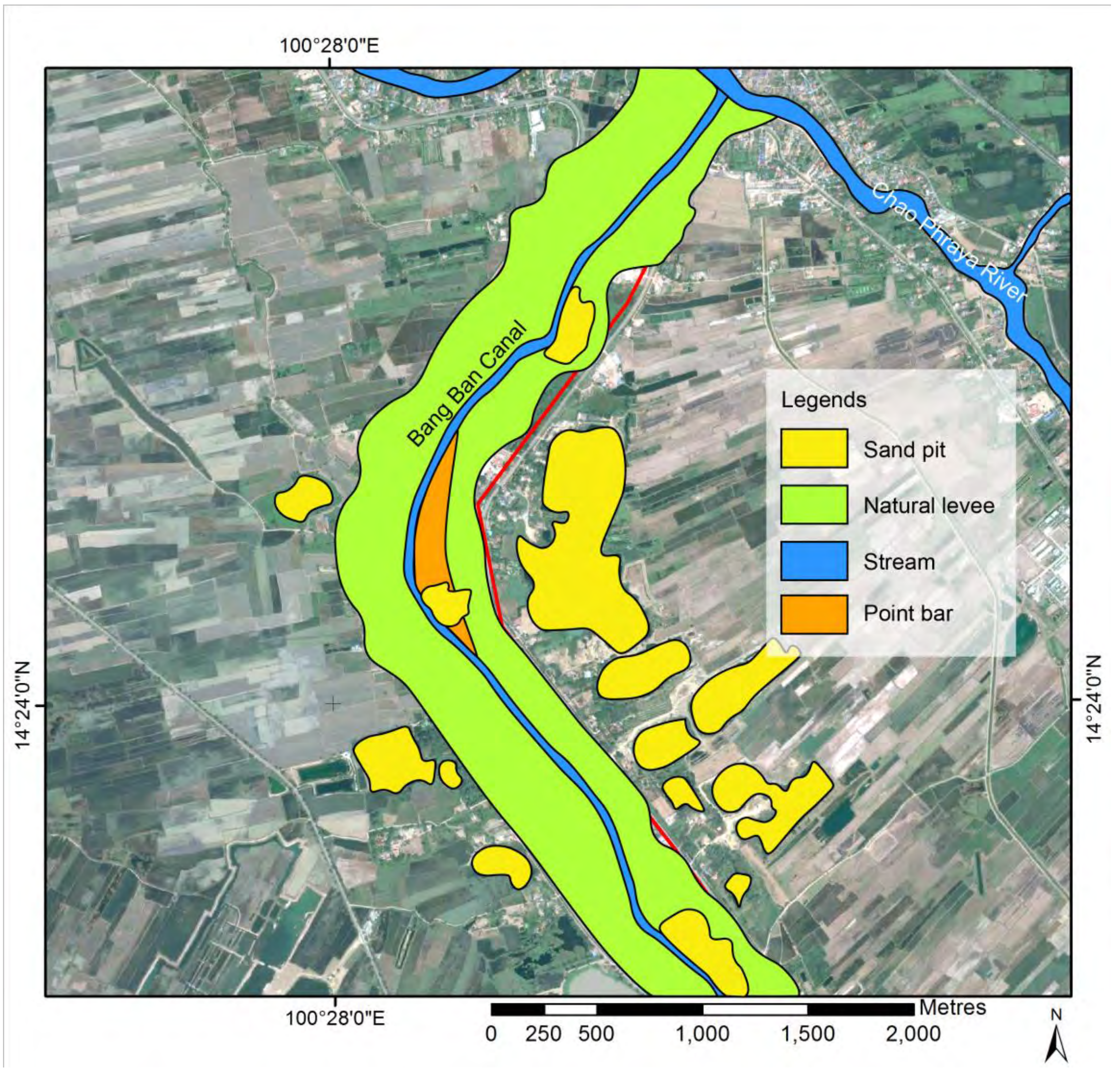


Figure 9. Bang Ban canal geomorphology

Figure 10. Sand pit opposite to the river bank at borehole BC1 location.

Figure 11. Bank slope near the borehole BC1 location.

4.2 SEDIMENT SAMPLES DESCRIPTION

This research analyses grain size distribution and water content of the soil samples. There are four boreholes which are BC1, BC2, BC3, and BC4.

4.2.1 BOREHOLE NO. BC1

Location: 14°25'05.2" N 100°28'36.6" E (14.418108, 100.476836)

Field record: We investigated river banks alongside Bang Ban canal from North to South. Local people stated that there are a few river bank failures at the North part of Bang Ban canal, however, we found the area that has chance of river bank failures.

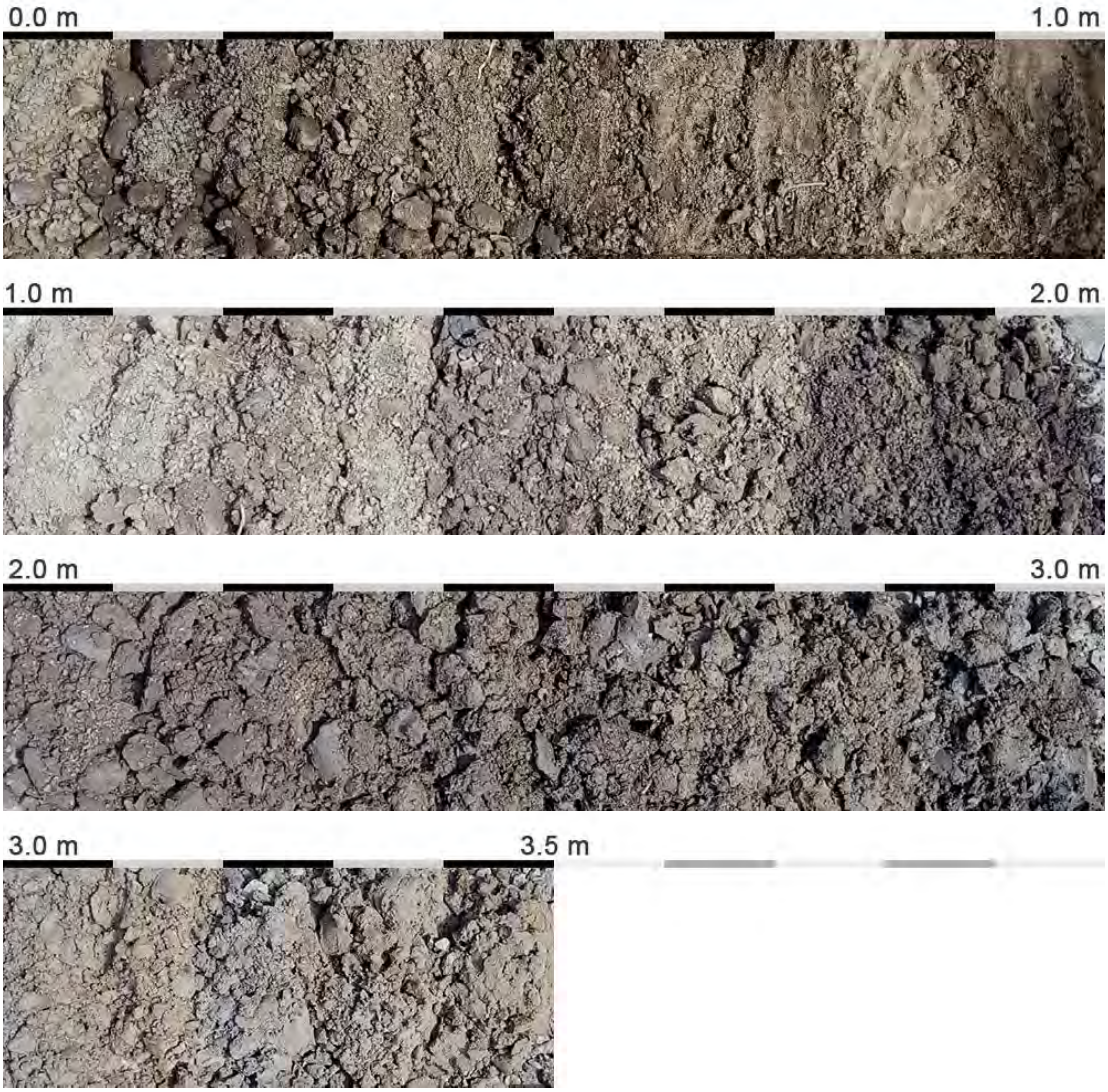


Figure 12. Soil samples from hand auger (BC1).

Table 4. Field description of soil from borehole no. BC1

Sample No. BC1	Volumetric Water Content	Field Description of Soil
0-10 cm	0.002 m^3/m^3	Brown silt
10-20	0.040	Brown clayey silt
20-30	0.055	Brown clayey silt
30-40	0.026	Brown silt
40-50	0.011	Brown very fine sand
50-60	0.060	Brown very fine sand
60-70	0.064	Brown very fine sand
70-80	0.063	Reddish brown fine sand
80-90	0.071	Reddish brown fine sand
90-100	0.071	Brown very fine sand
100-110	0.084	Brown very fine sand
110-120	0.069	Brown very fine sand
120-130	0.102	Brown very fine sand
130-140	0.116	Brown very fine sand
140-150	0.096	Brown clayey silt
150-160	0.112	Brown clayey silt
160-170	0.067	Brown very fine sand
170-180	0.100	Brown clayey silt
180-190	0.103	Brown silt
190-200	0.131	Brown silt
200-210	0.139	Brown silt
210-220	0.113	Brown silt
220-230	0.101	Brown clayey silt
230-240	0.144	Brown silty clay
240-250	0.185	Brown silty clay
250-260	0.174	Brown clayey silt
260-270	0.200	Brown clayey silt
270-280	0.249	Brown clayey silt
280-290	0.246	Brown clayey silt
290-300	0.164	Brown clayey silt
300-310	0.146	Red fine sand
310-320	0.158	Red fine sand
320-330	0.162	Reddish brown fine sand
330-340	0.170	Reddish brown fine sand
340-350	0.185	Reddish brown fine sand

4.2.2 BOREHOLE NO. BC2

Location: 14°24'08.0" N 100°28'19.5" E (14.402210, 100.472094)
Wat Bang Ban

Field record: Grey silt layer is found at the depth of 3.50 metres, therefore we inferred that this layer should be a long-run water table because grey colour indicates unexposed-to-air layer. However, actual water table is at the depth of 3.80 metres because water proportion increases immediately. This area, regarding to the core, is mostly composed of silt and sand with thin-interbedded-clay layer.

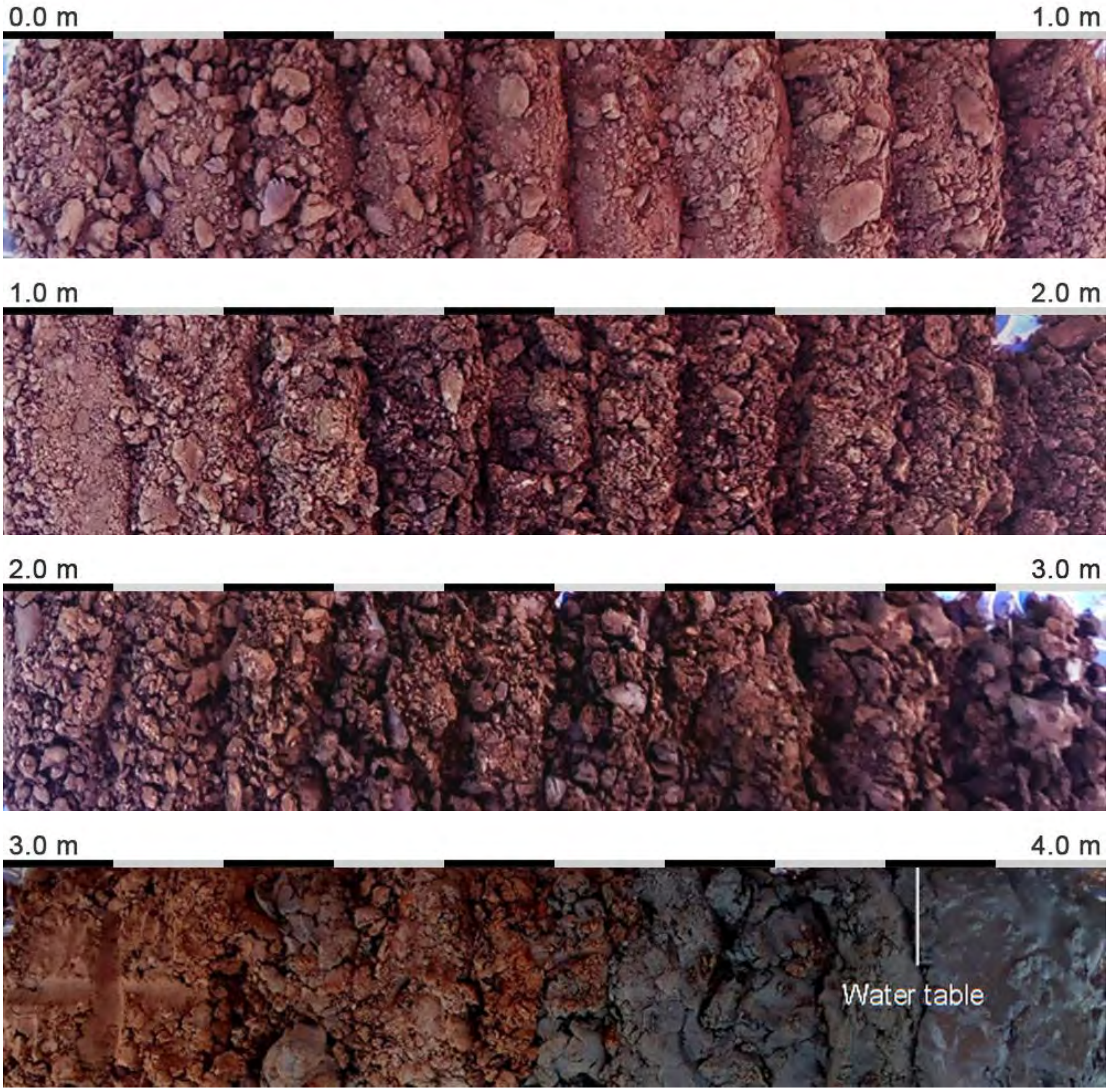


Figure 13. Soil samples from hand auger (BC2).

Table 5. Field description of soil from borehole no. BC2

Sample No. BC2	Volumetric Water Content	Field Description of Soil
0-10 cm	0.032 m^3/m^3	Brown silty sand
10-20	0.034	Brown silty sand
20-30	0.037	Brown silty sand
30-40	0.055	Brown silty sand
40-50	0.041	Brown silty sand
50-60	0.027	Brown silty sand
60-70	0.021	Brown silty sand
70-80	0.037	Brown silty sand
80-90	0.069	Brown silty sand
90-100	0.077	Brown silty sand
100-110	0.088	Brown clayey silt
110-120	0.1	Brown clayey silt
120-130	0.106	Brown clayey silt
130-140	0.106	Brown clayey silt
140-150	0.115	Brown clayey silt
150-160	0.089	Brown clayey silt
160-170	0.094	Brown clayey silt
170-180	0.155	Brown clayey silt
180-190	0.123	Brown silt
190-200	0.135	Brown silt
200-210	0.126	Brown silt
210-220	0.137	Brown silt
220-230	0.15	Brown clayey silt
230-240	0.172	Brown silty clay
240-250	0.145	Brown silty clay
250-260	0.146	Brown silty clay
260-270	0.164	Brown silty clay
270-280	0.172	Brown silty clay
280-290	0.142	Brown silty clay
290-300	0.14	Brown silty clay
300-310	0.151	Orangish very fine sand
310-320	0.145	Orangish very fine sand
320-330	0.259	Orangish very fine sand
330-340	0.253	Orangish very fine sand
340-350	0.31	Orangish very fine sand
350-360	0.315	Grey very fine sand
360-370	0.409	Grey very fine sand
370-380	0.403	Grey very fine sand
380-390	0.38	Grey very fine sand
390-400	0.423	Grey very fine sand

4.2.3 BOREHOLE NO. BC3

Location: 14°24'06.8" N 100°28'20.2" E (14.401886, 100.472290)
Wat Bang Ban

Field record: Sampling on 29th March 2017.

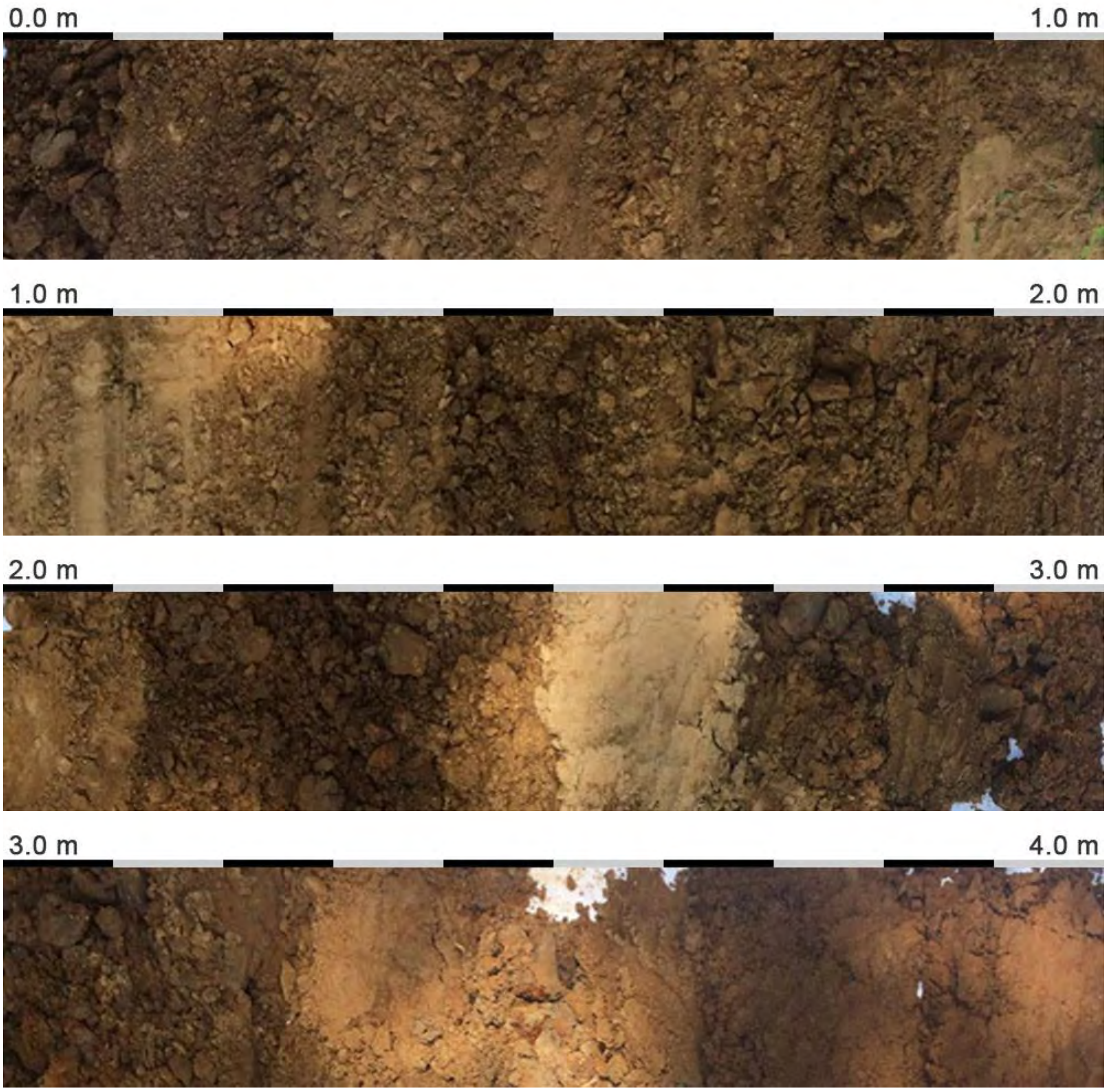


Figure 14. Soil samples from hand auger (BC3).

Table 6. Field description of soil from borehole no. BC3.

Sample No. BC3	Volumetric Water Content	Field Description of Soil
0-20 cm	0.058 m^3/m^3	Reddish brown silty sand
20-30	0.040	Orangish brown silty sand
30-50	0.011	Orangish brown silty sand
50-60	0.014	Orangish brown silty sand
60-70	0.030	Orangish brown silty sand
70-80	0.035	Orangish brown silty sand
80-90	0.021	Orangish brown silty sand
90-100	0.014	Orangish brown silty sand*
100-110	0.039	Orangish brown fine sand
110-120	0.020	Orangish brown fine sand
120-130	0.057	Orangish brown fine sand
130-140	0.123	Orangish brown fine sand
140-150	0.168	Reddish brown clayey sand
150-160	0.089	Reddish brown clayey sand
160-170	0.101	Orangish brown fine sand
170-180	0.111	Orangish brown fine sand
180-200	0.146	Orangish brown fine sand
200-210	0.198	Orangish brown fine sand
210-220	0.324	Orangish brown clayey sand
220-230	0.281	Dark brown sandy clay
230-240	0.192	Dark brown sandy clay
240-250	0.134	Orangish brown silty sand
250-270	0.014	Light brown fine sand
270-280	0.176	Orangish brown clayey sand
280-290	0.091	Orangish brown fine sand
290-300	0.227	Orangish brown clayey sand
300-310	0.260	Orangish brown clayey sand**
310-320	0.183	Orangish brown clayey sand
320-340	0.156	Orangish brown fine sand
340-360	0.065	Orangish brown fine sand
360-380	0.100	Orangish brown medium sand
380-400	0.285	Orangish brown medium sand

** sharp contact with orangish brown fine sand below.*

***thin layer of clay is interbedded at the middle of the core sample.*

4.2.4 BOREHOLE NO. BC4

Location: 14°24'08.5" N 100°28'18.8" E (14.402367, 100.471885)
Wat Bang Ban

Field record: Due to storm during field survey, hand auger was interrupted. Therefore, first 1.50 metres of soil were sampled on 29th March 2017 while the rest were sampled on 17th April 2017. Interpretation of water content in this borehole should be limited.

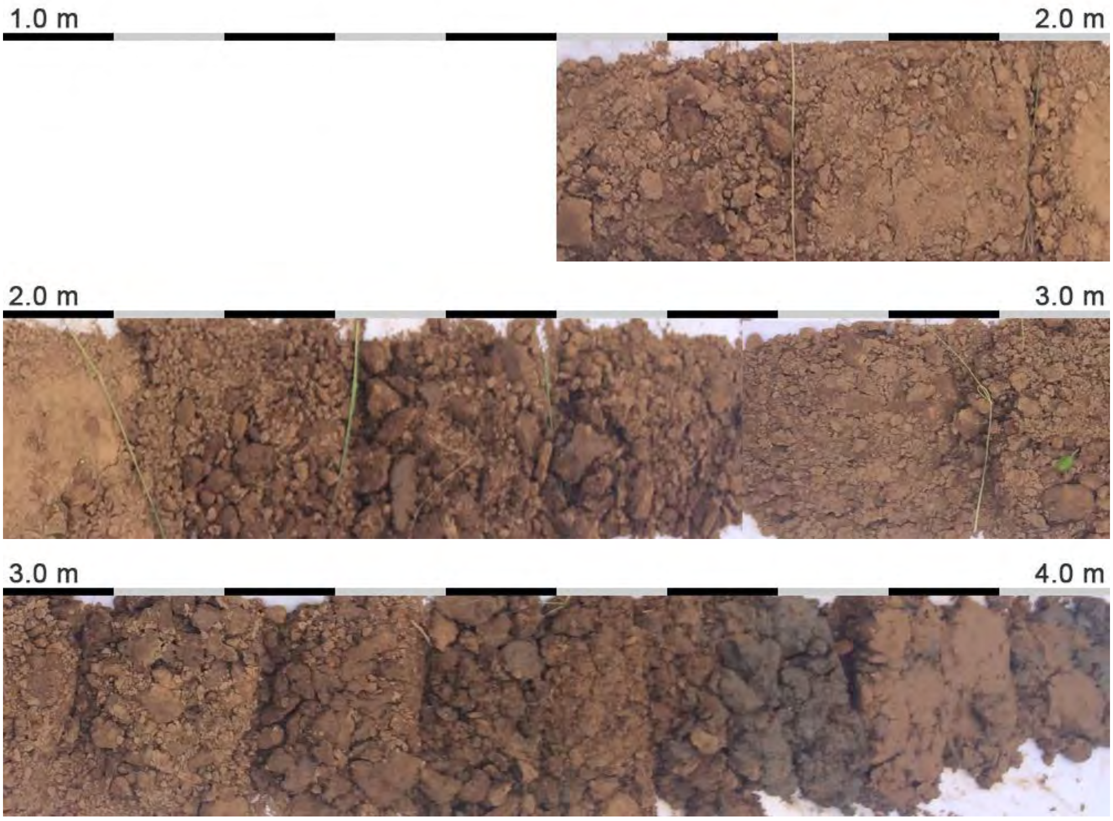


Figure 15. Soil samples from hand auger (BC4).

Table 7. Field description of soil from borehole no. BC4.

Sample No. BC4	Volumetric Water Content	Field Description of Soil
0-20 cm	0.049 m^3/m^3	Reddish brown clayey sand
20-30	0.055	Reddish brown clayey sand
30-40	0.030	Reddish brown clayey sand
40-60	0.026	Reddish brown clayey sand
60-70	0.050	Reddish brown clayey sand
70-80	0.044	Reddish brown clayey sand
80-90	0.042	Reddish brown clayey sand
90-100	0.026	Reddish brown clayey sand
100-110	0.033	Reddish brown clayey sand
110-120	0.026	Reddish brown clayey sand
120-130	0.026	Reddish brown clayey sand
130-140	0.027	Reddish brown clayey sand
140-150	0.021	Reddish brown clayey sand
150-170	0.027	Reddish brown sandy clay
170-190	0.023	Reddish brown sandy clay
190-210	0.025	Reddish brown very fine sand
210-230	0.035	Dark brown sandy clay
230-250	0.033	Dark brown sandy clay
250-270	0.032	Dark brown sandy clay
270-285	0.039	Dark brown sandy clay
285-300	0.047	Dark brown sandy clay
300-315	0.039	Dark brown sandy clay
315-330	0.081	Dark brown sandy clay
330-340	0.062	Dark brown sandy clay
340-350	0.087	Dark brown sandy clay
350-360	0.089	Dark brown sandy clay
360-370	0.230	Grey very fine sand
370-380	0.312	Orangish brown fine sand
380-390	0.220	Orangish brown fine sand
390-400	0.225	Grey fine sand

4.3 WATER CONTENT

Soil moisture or water content in this study area seems to increase with an increase in depth; however, water content in mud layer increases significantly comparing with adjacent layers. An increase of water content in mud layer is clear during dryer time.

Gravimetric Water Content

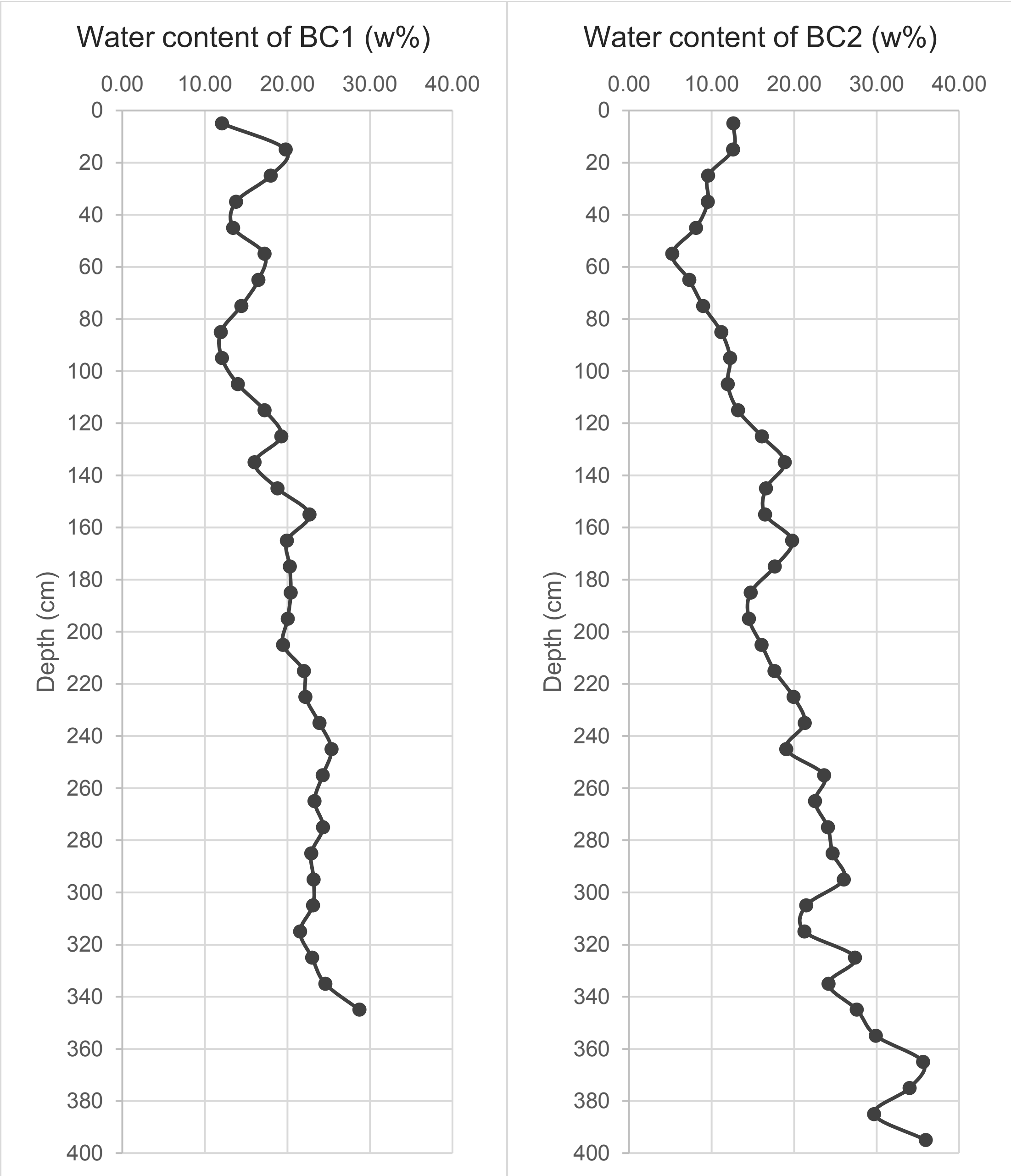


Figure 16. Gravimetric water content of BC1 and BC2 on 25th January 2017.

Volumetric Water Content

Volumetric water content is measured by using ProCheck which is an electronic equipment, however, the results are accurate comparing to gravimetric water content in samples from borehole BC1 and BC2.

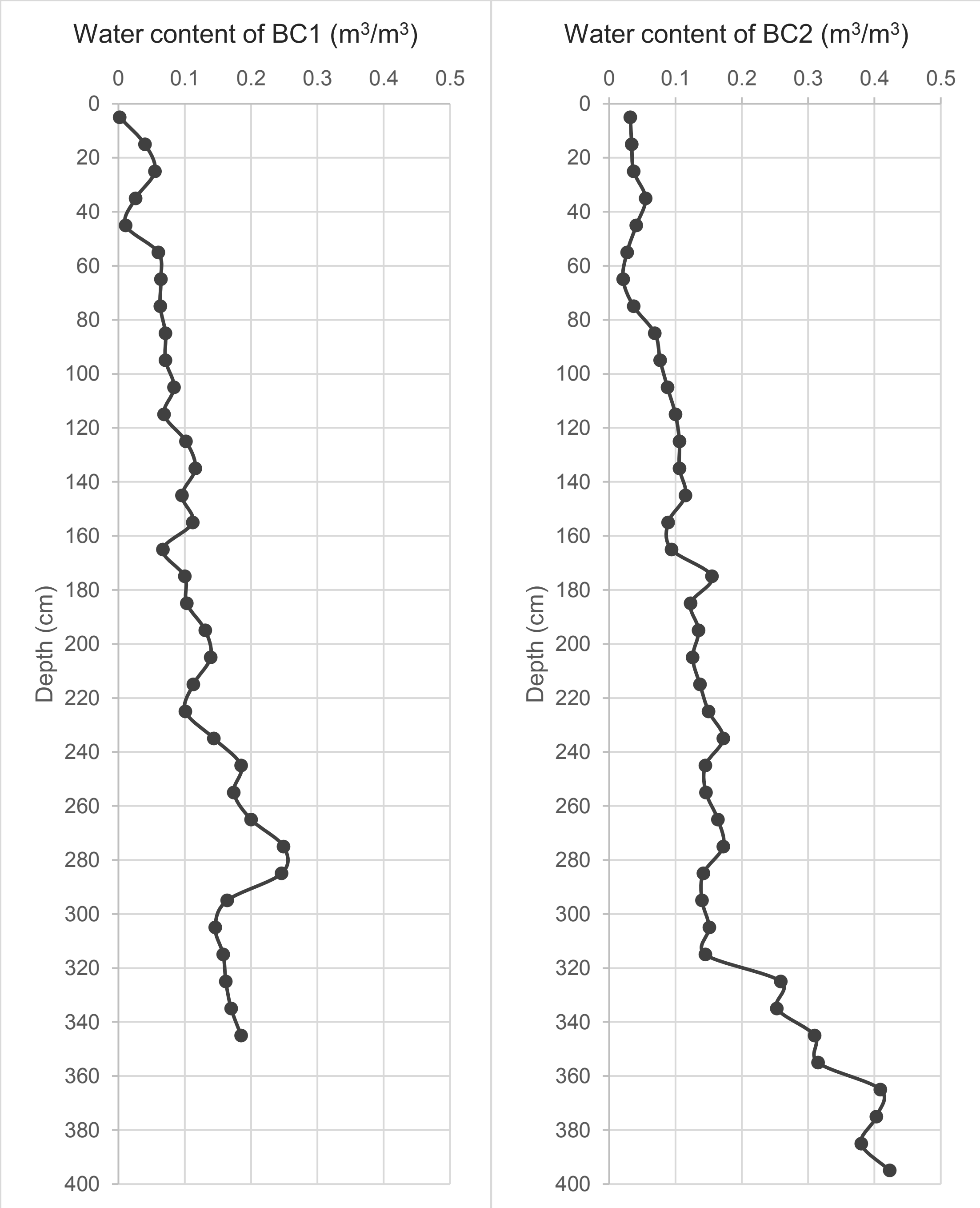


Figure 17. Volumetric water content of BC1 and BC2 on 25th January 2017.

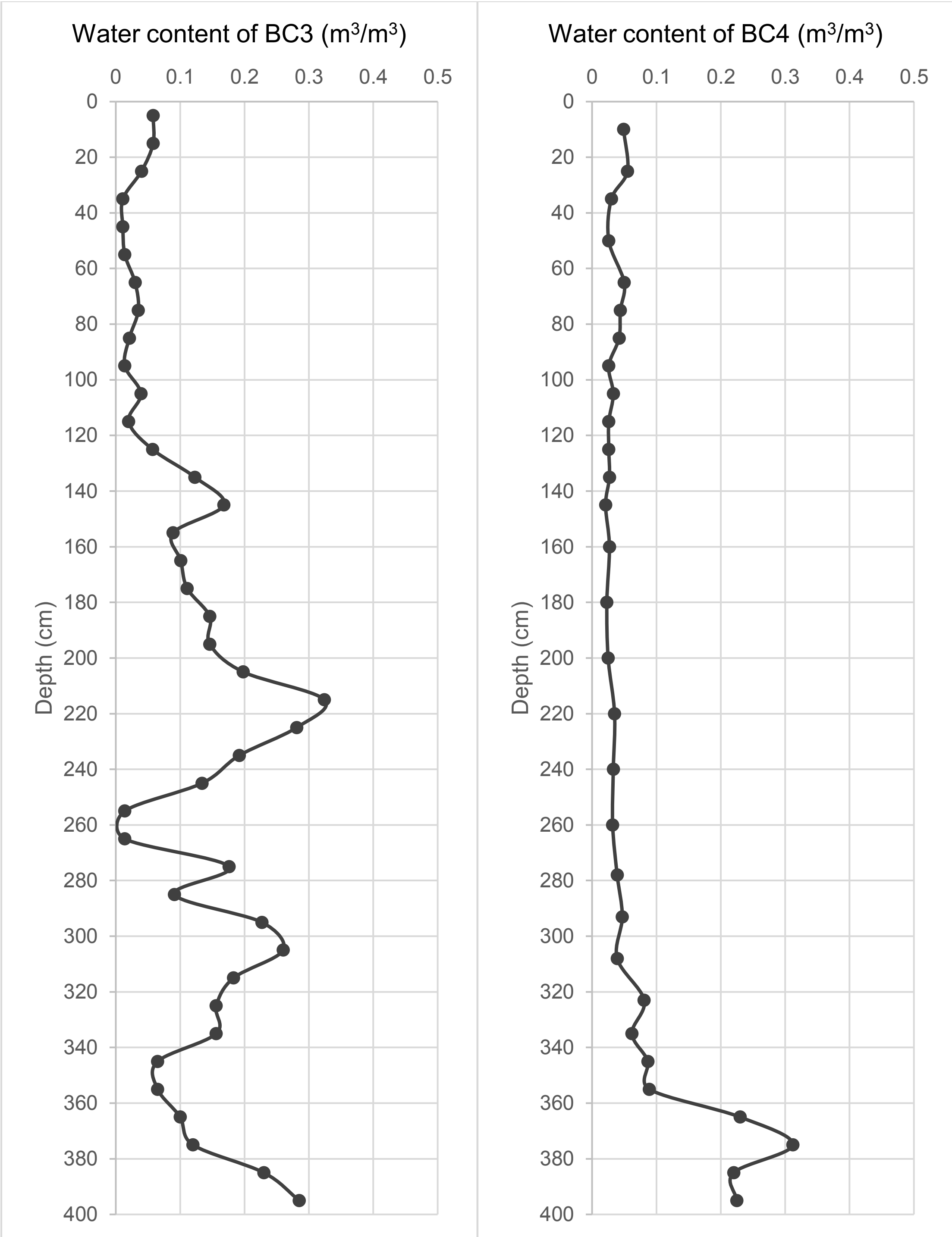


Figure 18. Volumetric water content of BC3 and BC4 on 29th March 2017.

4.4 GRAIN SIZE DISTRIBUTION

In every borehole except BC2, mean grain size of soil changes at the depth of 3 metres approximately. The phi values decrease with an increase of depth. The results can be concluded that materials of the lower part of river banks are coarser than the upper part.

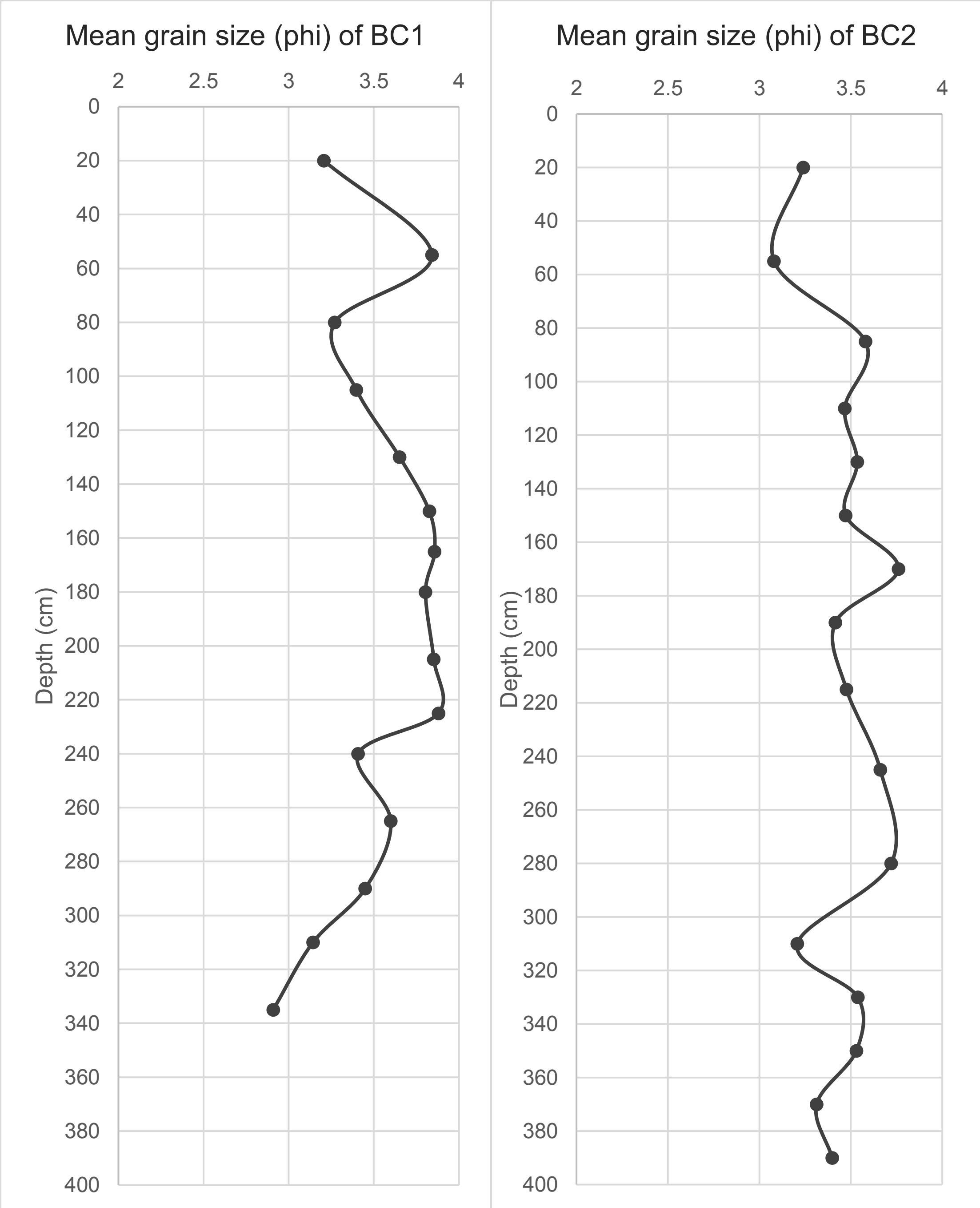


Figure 19. Mean grain size of soil samples from BC1 and BC2.

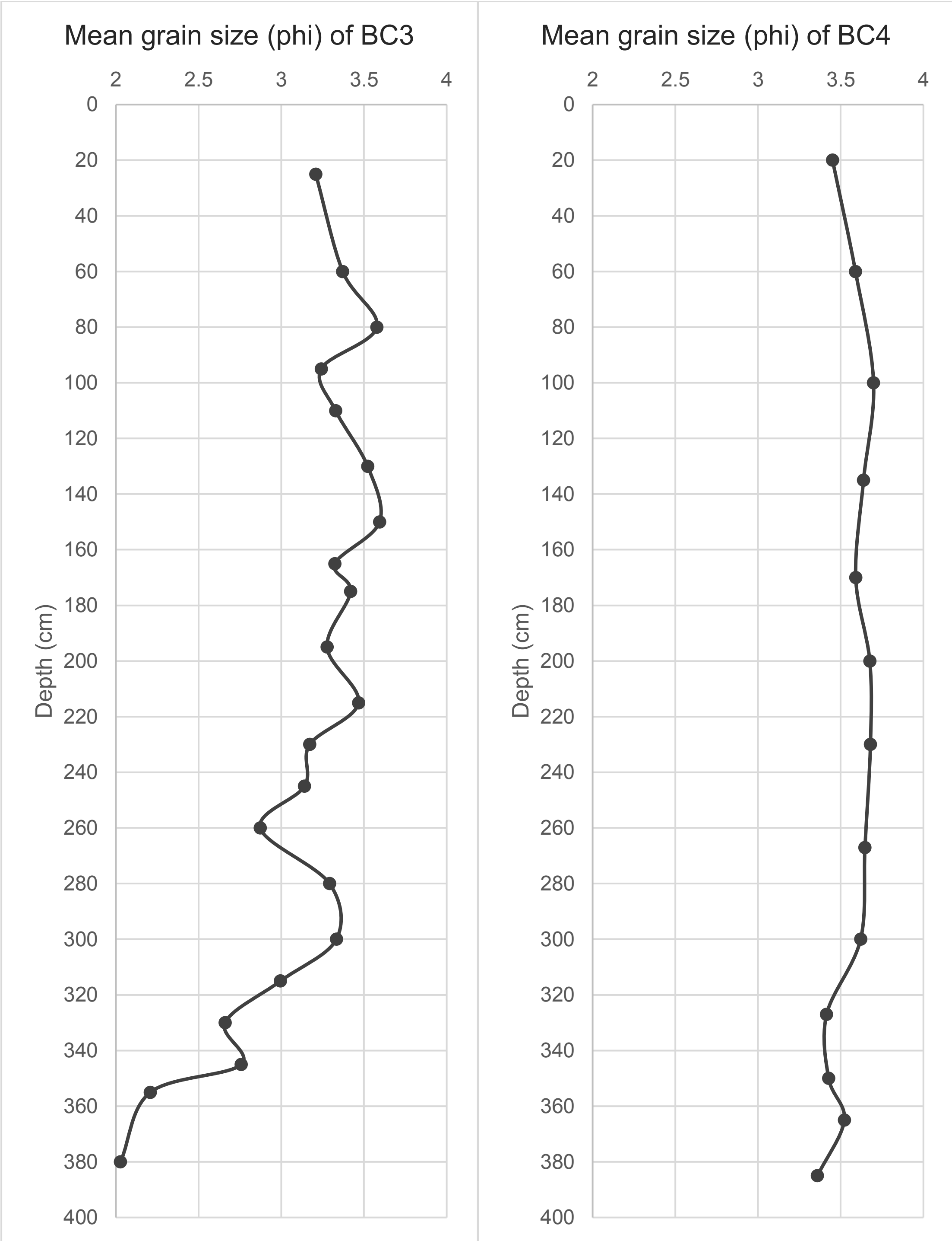


Figure 20. Mean grain size of soil samples from BC3 and BC4.

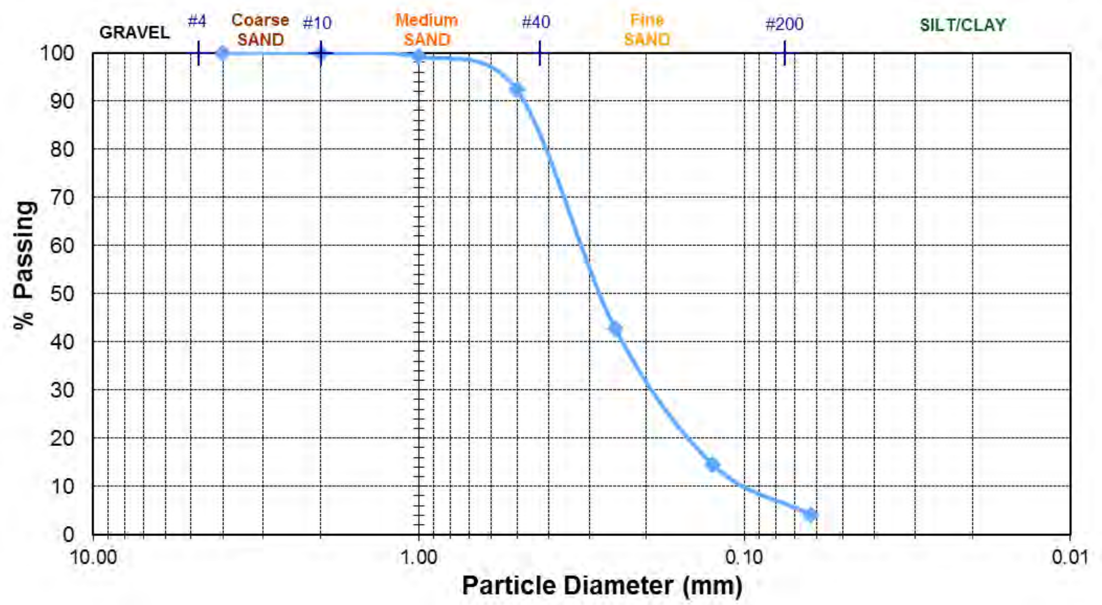


Figure 21. Grain size distribution of fine sand (only found in BC3).

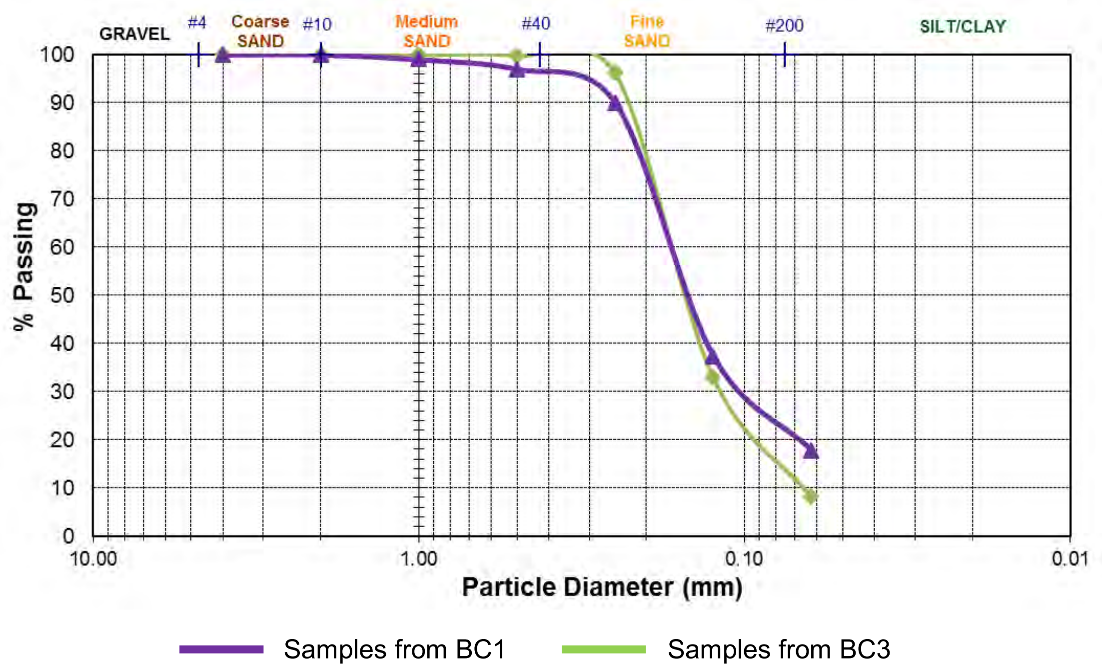


Figure 22. Grain size distribution of fine sand with silt/clay.

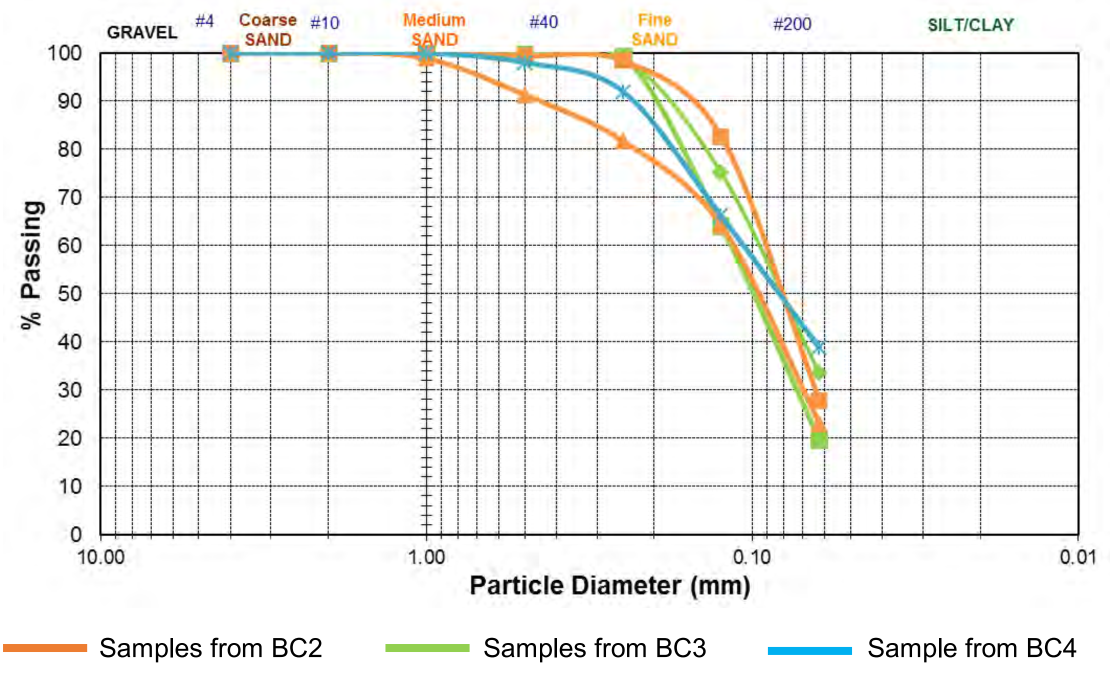


Figure 23. Grain size distribution of very fine sand with silt/clay.

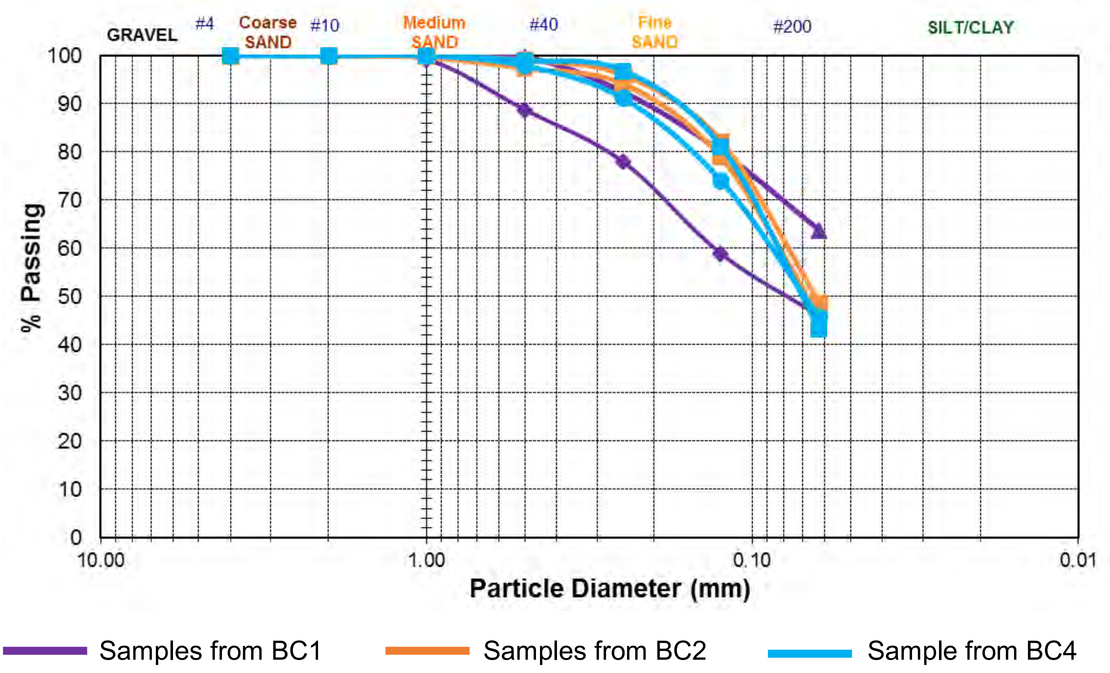


Figure 24. Grain size distribution of silt/clay.

4.5 STRATIGRAPHY

BC2, BC3, and BC4 have mostly same soil sequence. From top to bottom; very fine sand with silt/clay interbedded with mud (silt/clay) layers, and the lowest parts are very fine/fine sand with silt/clay; mud layers are absent in these parts. Exception for BC1, there is no very fine sand with silt/clay layer at the top, but the lower part is similar to the rest.

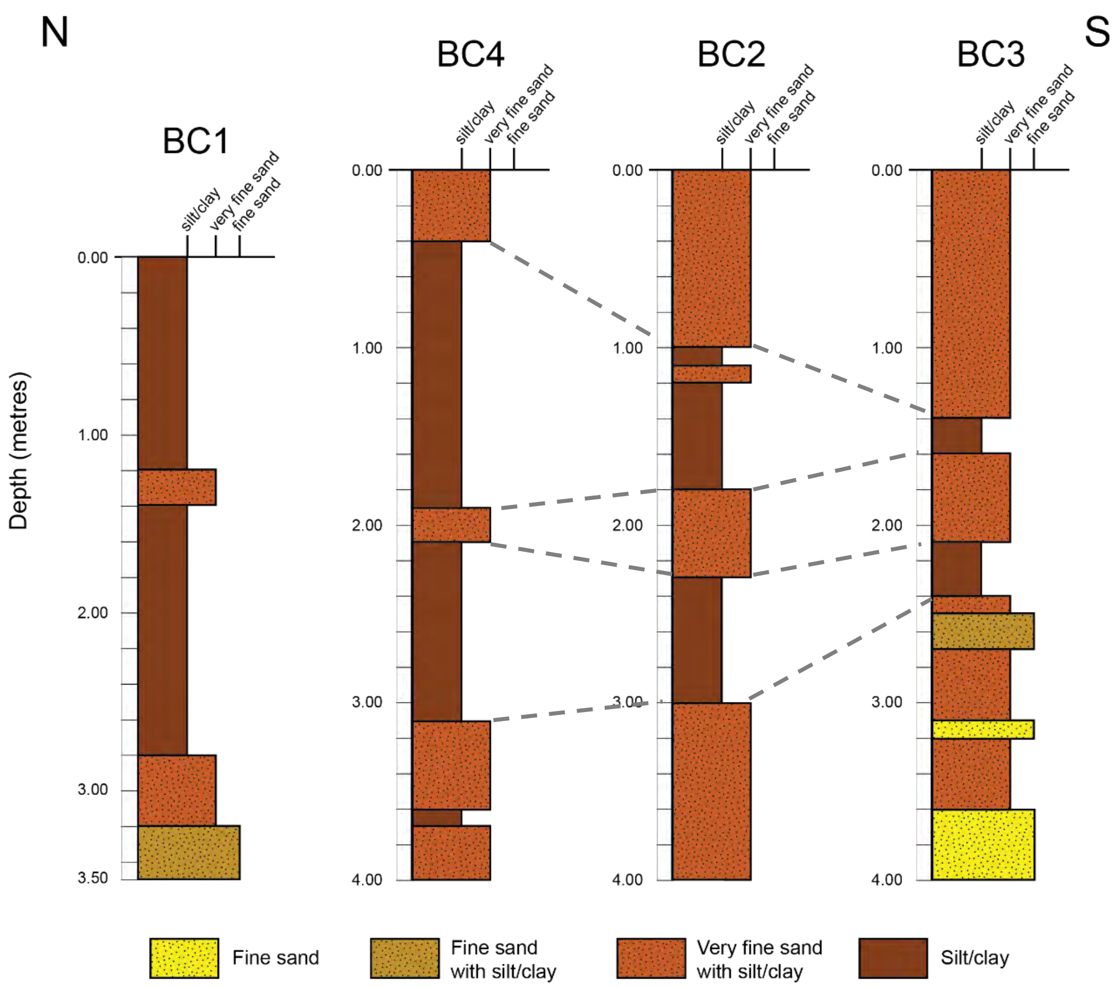


Figure 25. Stratigraphy of all boreholes in the study area.

4.6 GPR RESULTS

There are 4 lines of GPR survey. Line 1 is surveyed in NW-SE direction; its purpose is to find structures which are parallel to stream line. Line 2, 3, and 4 are surveyed in W-E direction of which purpose is to find structures which are perpendicular to stream line.

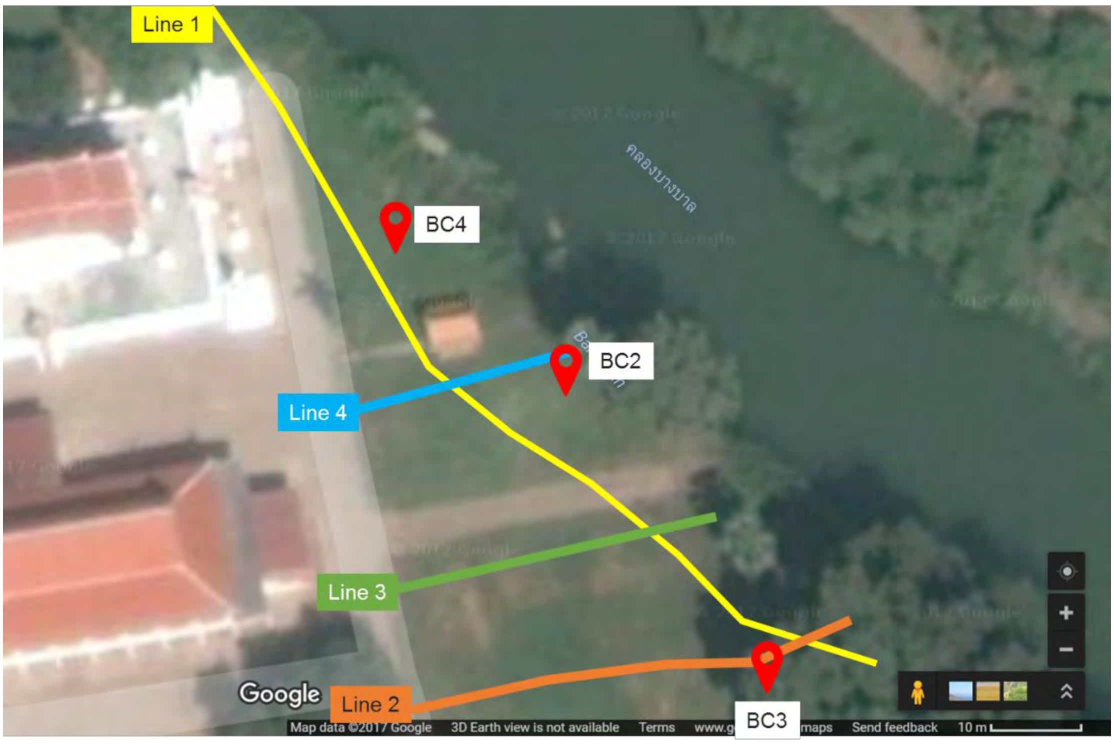


Figure 26. GPR survey lines shown in the map. (Google Maps, 2017)

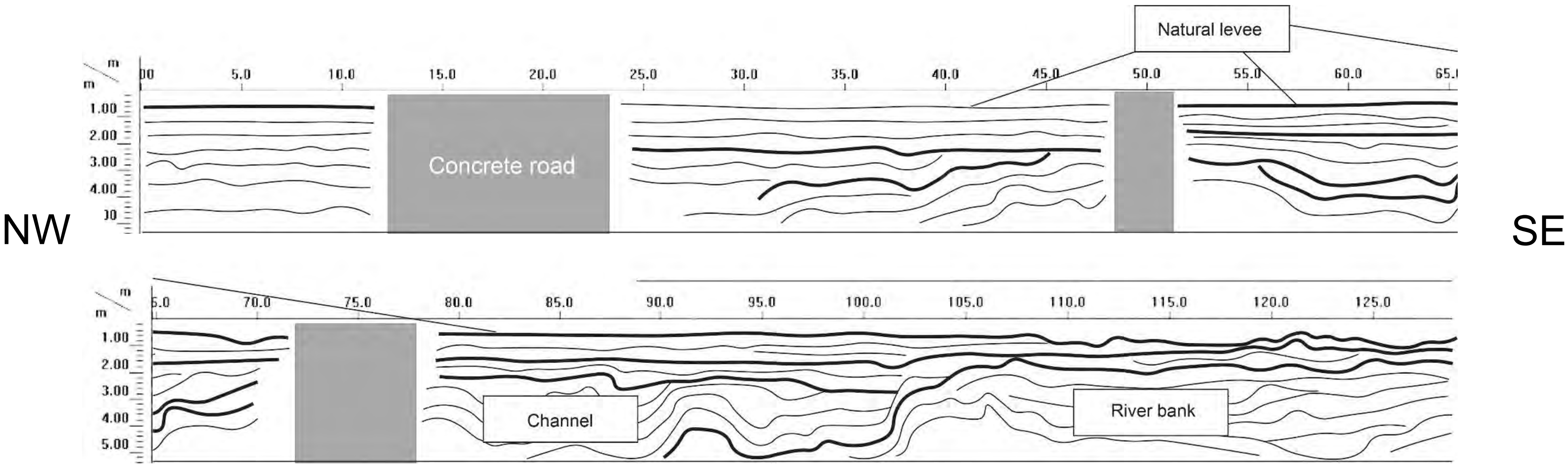


Figure 27. Interpretation results of GPR survey line 1.

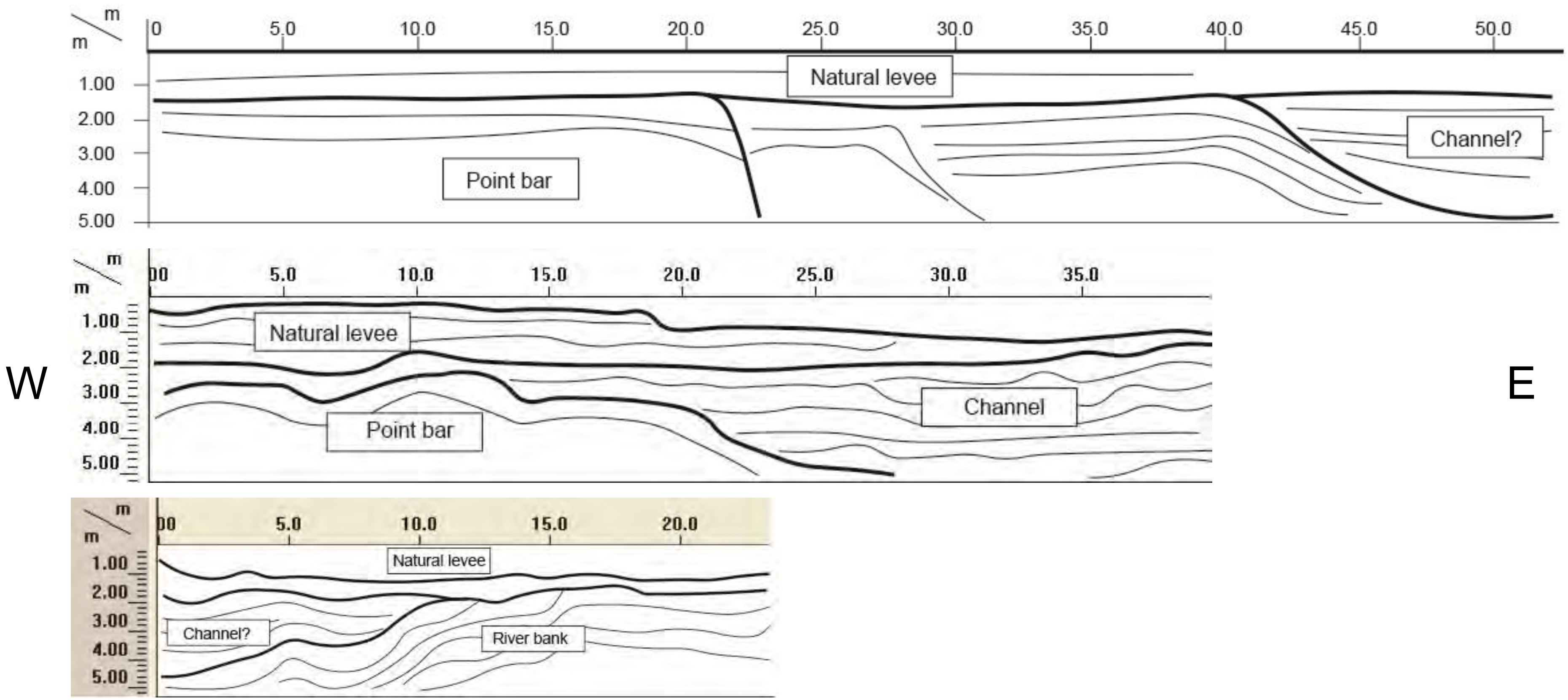


Figure 28. Interpretation results of GPR survey line 2, 3, and 4 (from top to bottom).

Interpretation

According to GPR results, there are unconformity at the depth of 2 to 3 metres in every survey line. This can be interpreted as a top layer which deposited in recent time, natural levee. The lower part has complex structures, however, can be classified as old point bar, old river bank, and old channel. These interpretations correspond to the stratigraphy of river bank in Wat Bang Ban that the upper part is mainly composed of silt and clay which is natural levee materials while the lower part is mainly composed of sand which is fluvial deposits in meandering stream.

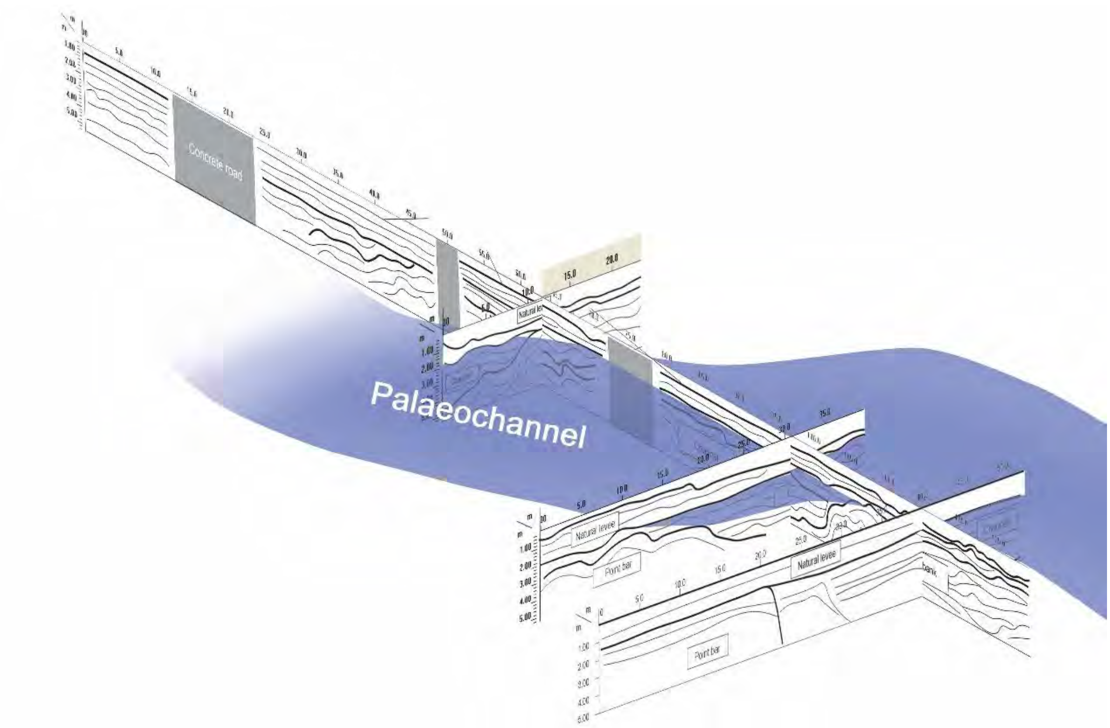


Figure 29. Fence diagram of GPR results leads to interpretation that Bang Ban Canal was a meandering stream.

4.7 RIVER BANK HEIGHT PROFILE

The river bank height profile is useful for determining the slope of the river bank. When the profile is created, the slope can also be calculated.

Figure 30. River bank height profile survey line. (Google Maps, 2017)

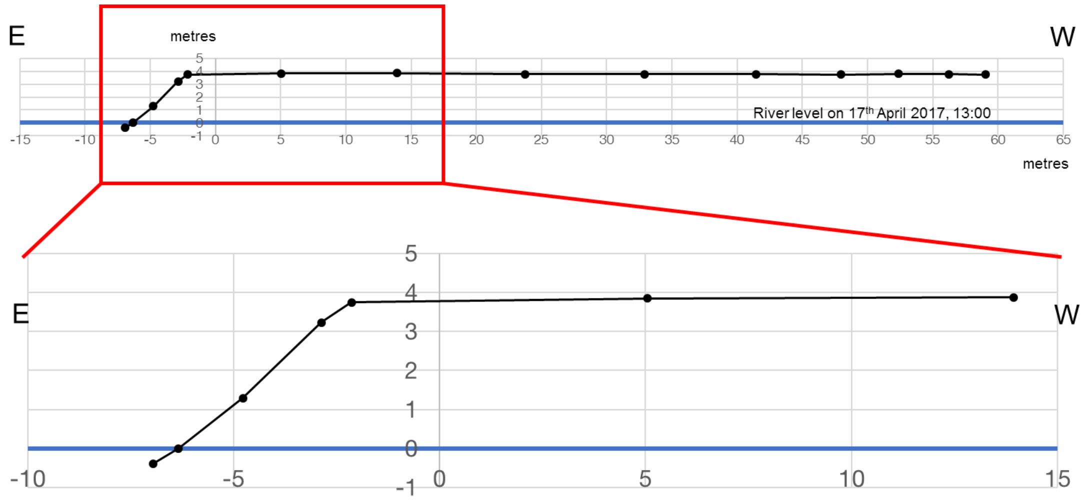


Figure 31. River bank height profile

Bank height = 4.13+2.07 = 6.2 metres (estimated)

Bankfull height = 2.07 metres

Bank/bankfull height ratio = 6.2/2.07 = 3.00

Bank slope = 0.8582

Bank slope = 40.64°

True bank slope = 45.66°

According to BEHI (Rosgen, 2001), Bank angle category is low risk of erodibility and bank height category is extreme risk of erodibility.

4.8 RIVER BANK EROSION POTENTIAL AT WAT BANG BAN

Bank Erosion Hazard Index (BEPI) is used in this research for evaluating the risk of river bank failure. They consist of seven factors which are bank height ratio, root depth ratio, root density, bank angle, surface protection, bank materials, and stratification.

Table 8. BEHI score of river bank in Wat Bang Ban.

	BEHI score		
Variable	**Value**	**Index**	**Category**
Bank Ht. Ratio	3	10	Extreme
Root Depth (%)	55-30	5	Moderate
Root Density (%)	55-30	5	Moderate
Bank Angle (deg)	45	4	Low
Surface Protection (%)	70	3	Low
Bank Materials	Sand at lower part	10	(adjust.)
Stratification	Presence	5	(adjust.)
Total		42	Very High

According to table 9., we can conclude that river bank in Wat Bang Ban is at very high risk of erodibility and this can lead to river bank failure. Bank height ratio and bank materials mainly contribute BEHI score. Therefore, during rapid drawdown, river bank should be monitored carefully because of the higher bank height ratio and increase of pore pressure in soils.

Figure 32. Vegetation at Bang Ban canal.

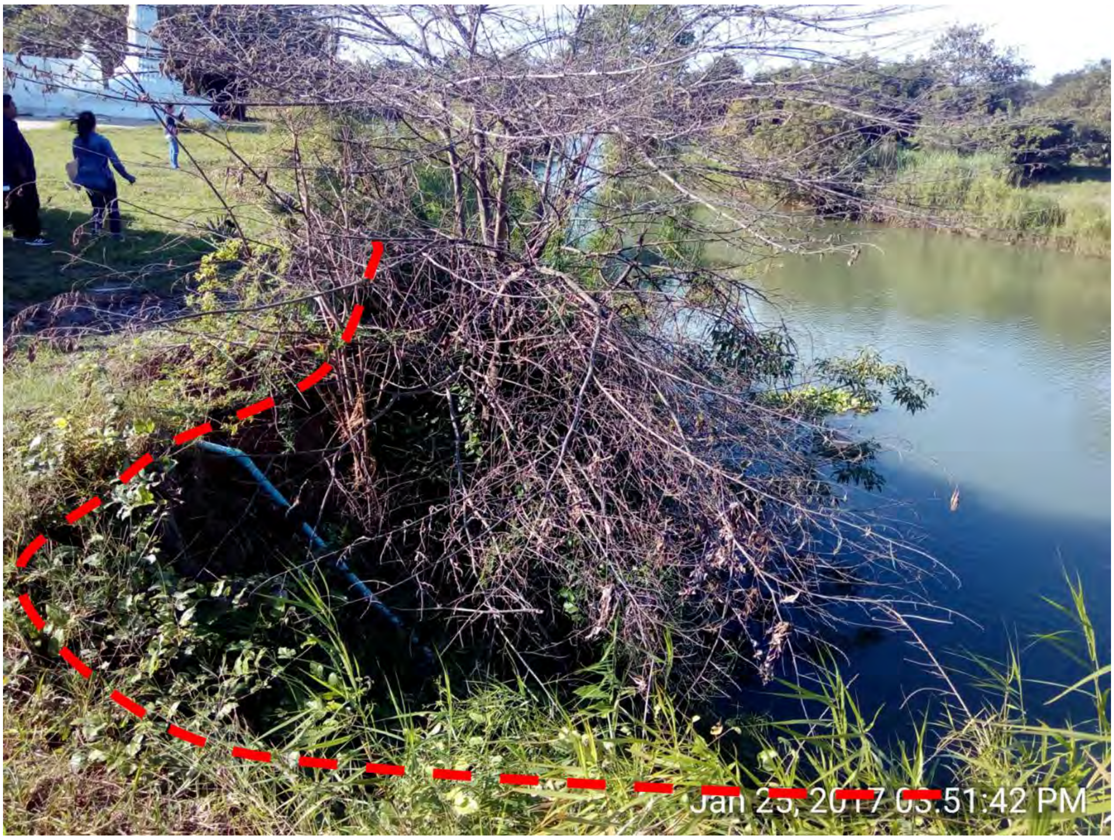


Figure 33. River bank failure at Wat Bang Ban.

4.9 RELATIONSHIP BETWEEN WATER CONTENT AND GRAIN SIZE

In borehole BC3, the relationship between water content and mean grain size is positive. Even water content usually increase with depth, there is a dramatic increase of water content in cohesive layers in which silt and clay are main materials. However, in sand layers, water content drops. This relationship corresponds to the properties of soil materials. As clay has low permeability and sand has high permeability, water should be stored in silt/clay layer.

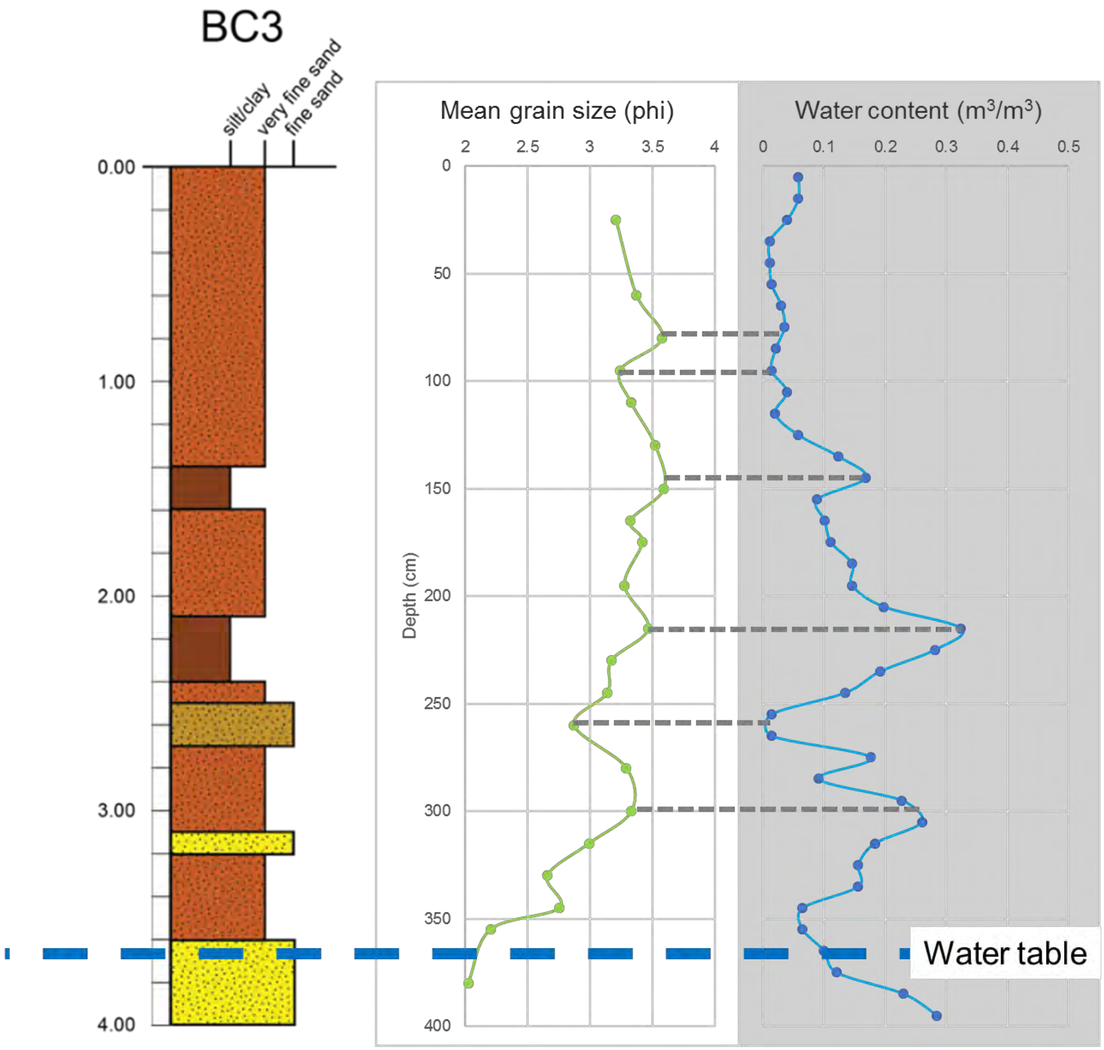


Figure 34. Relationship between water content and mean grain size.

5 CONCLUSIONS

In every borehole, mean grain size of soil changes at the depth of 3 metres approximately. Upper part of river bank (3 metre-deep) mainly consists of silt/clay materials (some layers are very fine sand with silt/clay). Lower part of river bank consists of coarser materials (fine sand to very fine sand). According to GPR results, the upper part can be interpreted as natural levee, while the lower part is old point bar.

Bang Ban Canal's bank type is composite bank. The upper part is cohesive soil which is more resistant than the lower part, cohesionless soil. If river level lowers to the lower part, the erosion rate will increase significantly. When the lower part is eroded, river bank failures will occur easily.

However, there are limitations in this research, as hand auger cannot dig deeper than 4 metres from the surface, the deepest soil layer which can be sampled is a 4 metre-deep-soil which is at the river level during field survey. As we cannot sample soil deeper than 4 metres, this interpretation should be limited.

Moreover, the river bank height from water level at Wat Bang Ban is 4.13 metres (on 17th April 2017) which is then calculated and considered as very high risk in BEHI. Bank slope is 45 degrees which is considered as low risk. When all factors are calculated, according to Bank Erosion Hazard Index (BEHI), river bank at Wat Bang Ban is classified as very high risk of erodibility.

5.1 PROPOSED MECHANISMS OF FAILURE

The results show that the river bank of Bang Ban Canal consists of 2 parts which are the upper cohesive layer and the lower cohesionless layer. The stratigraphy of Bang Ban Canal area is similar to the rivers of Niger Delta, whose upper part of the stratigraphy is cohesive silty clay while the lower part is cohesionless sand.

The normal mechanism of river bank erosion is that erosion rate of the lower cohesionless bank layer is faster than the upper cohesive bank layer which develops the overhangs of the upper cohesive materials. This can lead to river bank failure. However, during rapid drawdown or after flooding, the main factors of river bank failure are river bank height ratio and an increase in pore pressure in soil.

5.2 RECOMMENDATIONS

We found that the river bank failure tends to occur in the residential area more than the unused land. This may be caused by the lack of vegetation; there is no root to bond soil together. Therefore, to grow plants along the river bank can alleviate river bank failure.

During rapid drawdown, river bank should be monitored carefully because of higher bank height ratio and pore pressure increase. Moreover, there are water gates in Bang-Ban Canal, to open or close water gates should be done slowly.

To build river bank protection structure can cause the opposite bank to face severe erosion, there should be an explicit study in the area before build it.

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APPENDIX

SIEVE ANALYSIS RAW DATA

Table 9. Raw data of grain size distribution of borehole BC1 and BC2.

Borehole	Depth (cm)	Retained (%)							
		#5	#10	#18	#35	#60	#120	#230	pan
BC1	0-40	0.00	0.07	0.81	10.40	10.73	19.09	12.87	46.03
	40-70	0.00	0.00	0.00	0.18	0.66	14.78	33.59	50.78
	70-90	0.13	2.80	6.51	7.07	5.03	7.01	15.31	56.14
	90-120	0.31	2.16	4.23	4.64	4.06	11.67	19.84	53.09
	120-140	0.00	0.00	0.00	0.12	7.07	12.48	38.17	42.16
	140-160	0.00	0.00	0.15	0.83	1.24	13.19	33.24	51.35
	160-170	0.00	0.00	0.15	0.18	7.25	12.37	16.31	63.75
	170-190	0.00	0.00	0.00	0.22	0.60	15.72	35.48	47.98
	190-220	0.00	0.00	0.00	0.33	0.76	16.40	28.34	54.17
	220-230	0.00	0.00	0.09	0.34	1.33	16.21	23.82	58.21
	230-250	0.00	0.15	0.91	5.63	9.71	16.46	19.13	48.01
	250-280	0.00	0.00	0.06	0.96	4.11	20.66	31.68	42.52
	280-300	0.00	0.00	0.37	2.88	3.62	24.81	30.97	37.34
	300-320	0.47	3.30	5.46	3.71	1.92	16.62	31.47	37.04
	320-350	0.24	1.40	2.76	1.83	0.99	52.71	19.52	20.55
BC2	0-40	0.00	0.00	0.59	5.91	10.95	22.53	21.90	38.12
	40-70	0.00	0.00	1.20	7.55	9.59	17.54	41.04	23.08
	70-100	0.00	0.00	0.07	0.54	1.05	15.73	54.75	27.85
	100-120	0.00	0.00	0.00	0.43	6.91	14.99	50.91	26.76
	120-140	0.00	0.00	0.00	1.92	5.83	16.03	39.29	36.94
	140-160	0.00	0.00	0.00	2.06	10.55	13.15	36.64	37.60
	160-180	0.00	0.00	0.00	0.88	3.12	13.78	33.53	48.69
	180-200	0.00	0.00	0.00	0.96	1.91	31.07	36.76	29.30
	200-230	0.00	0.00	0.00	1.49	1.56	27.19	37.34	32.41
	230-260	0.00	0.00	0.30	2.34	3.16	15.35	32.87	45.98
	260-300	0.00	0.00	0.05	0.52	2.37	17.87	32.73	46.45
	300-320	0.00	0.00	0.34	1.37	2.16	40.16	35.29	20.69
	320-340	0.00	0.00	0.01	0.19	4.22	19.01	44.66	31.90
	340-360	0.00	0.00	0.01	0.31	6.59	15.06	45.80	32.23
	360-380	0.00	0.00	0.49	2.53	10.95	19.32	34.69	32.03
	380-400	0.00	0.00	0.00	0.15	7.59	24.81	37.09	30.35

Table 10. Raw data of grain size distribution of borehole BC3 and BC4.

Borehole	Depth (cm)	Retained (%)							
		#5	#10	#18	#35	#60	#120	#230	pan
BC3	0-50	0.00	0.00	0.35	3.98	18.07	15.19	26.92	35.49
	50-70	0.00	0.00	0.02	0.41	9.84	19.37	42.87	27.49
	70-90	0.00	0.00	0.01	0.22	0.70	23.85	41.55	33.67
	90-100	0.00	0.00	0.00	0.50	1.02	39.65	41.48	17.35
	100-120	0.00	0.00	0.01	0.20	0.49	35.27	44.35	19.69
	120-140	0.00	0.00	0.02	0.30	0.64	21.70	51.20	26.14
	140-160	0.00	0.00	0.01	0.24	0.87	23.80	39.33	35.75
	160-170	0.00	0.00	0.03	0.49	5.60	27.08	44.45	22.35
	170-180	0.00	0.00	0.03	0.39	5.05	22.07	47.10	25.36
	180-210	0.00	0.00	0.00	0.01	7.22	31.63	37.35	23.78
	210-220	0.00	0.00	0.05	0.58	9.64	18.37	35.03	36.32
	220-240	0.00	0.00	1.73	7.93	15.38	14.22	17.86	42.88
	240-250	0.00	0.00	0.50	1.37	6.02	39.17	31.60	21.35
	250-270	0.00	0.00	0.00	0.17	3.61	63.19	24.81	8.23
	270-290	0.00	0.00	0.04	0.38	10.37	24.36	39.25	25.59
	290-310	0.00	0.00	0.04	0.65	10.51	24.17	34.00	30.62
	310-320	0.00	0.00	0.04	0.40	13.11	42.85	23.65	19.95
	320-340	0.00	0.00	0.00	1.61	16.29	52.34	23.97	5.78
	340-350	0.00	0.00	0.16	6.39	19.79	32.70	23.09	17.86
	350-360	0.00	0.51	1.95	4.85	40.40	31.44	12.92	7.94
	360-400	0.00	0.06	0.72	6.93	49.42	28.42	10.41	4.04
BC4	0-40	0.00	0.00	0.00	1.94	6.07	25.79	27.36	38.83
	40-80	0.00	0.00	0.00	2.08	6.76	17.10	28.26	45.81
	80-120	0.00	0.00	0.00	1.10	2.10	15.74	37.91	43.14
	120-150	0.00	0.00	0.00	0.68	2.35	16.59	43.26	37.12
	150-190	0.00	0.00	0.00	1.03	3.03	21.80	34.09	40.06
	190-210	0.00	0.00	0.00	0.19	0.99	18.43	41.80	38.59
	210-250	0.00	0.00	0.00	1.06	2.80	20.49	28.40	47.26
	250-285	0.00	0.00	0.00	0.91	2.15	20.80	33.63	42.51
	285-315	0.00	0.00	0.00	0.02	2.51	22.32	35.67	39.47
	315-340	0.00	0.00	0.15	1.61	12.88	17.12	28.40	39.83
	340-360	0.00	0.00	0.05	0.70	13.97	16.27	29.74	39.26
	360-370	0.00	0.00	1.00	2.23	8.30	10.17	38.63	39.67
	370-400	0.00	0.00	0.06	0.39	4.28	28.80	41.75	24.72

Table 11. Mean grain size of BC1 and BC2.

Sample No.	Mean Grain Size	Wentworth Size Class
BC1		
0-40	3.21	Very fine sand
40-70	3.84	Very fine sand
70-90	3.27	Very fine sand
90-120	3.40	Very fine sand
120-140	3.65	Very fine sand
140-160	3.83	Very fine sand
160-170	3.86	Very fine sand
170-190	3.80	Very fine sand
190-220	3.85	Very fine sand
220-230	3.88	Very fine sand
230-250	3.41	Very fine sand
250-280	3.08	Very fine sand
280-300	2.33	Fine sand
300-320	3.14	Very fine sand
320-350	2.91	Fine sand
BC2		
0-40	3.24	Very fine sand
40-70	3.08	Very fine sand
70-100	3.58	Very fine sand
100-120	3.47	Very fine sand
120-140	3.54	Very fine sand
140-160	3.47	Very fine sand
160-180	3.76	Very fine sand
180-200	3.42	Very fine sand
200-230	3.48	Very fine sand
230-260	3.66	Very fine sand
260-300	3.72	Very fine sand
300-320	3.21	Very fine sand
320-340	3.54	Very fine sand
340-360	3.53	Very fine sand
360-380	3.31	Very fine sand
380-400	3.40	Very fine sand

Table 12. Mean grain size of BC3 and BC4.

Sample No.	Mean Grain Size	Wentworth Size Class
BC3		
0-50	3.21	Very fine sand
50-70	3.37	Very fine sand
70-90	3.58	Very fine sand
90-100	3.24	Very fine sand
100-120	3.33	Very fine sand
120-140	3.52	Very fine sand
140-160	3.59	Very fine sand
160-170	3.32	Very fine sand
170-180	3.42	Very fine sand
180-210	3.28	Very fine sand
210-220	3.47	Very fine sand
220-240	3.17	Very fine sand
240-250	3.14	Very fine sand
250-270	2.87	Fine sand
270-290	3.29	Very fine sand
290-310	3.33	Very fine sand
310-320	3.00	Fine sand
320-340	2.66	Fine sand
340-350	2.76	Fine sand
350-360	2.21	Fine sand
360-400	2.03	Fine sand
BC4		
0-40	3.45	Very fine sand
40-80	3.59	Very fine sand
80-120	3.70	Very fine sand
120-150	3.64	Very fine sand
150-190	3.59	Very fine sand
190-210	3.68	Very fine sand
210-250	3.68	Very fine sand
250-285	3.65	Very fine sand
285-315	3.62	Very fine sand
315-340	3.41	Very fine sand
340-360	3.43	Very fine sand
360-370	3.52	Very fine sand
370-400	3.36	Very fine sand

GPR RAW DATA

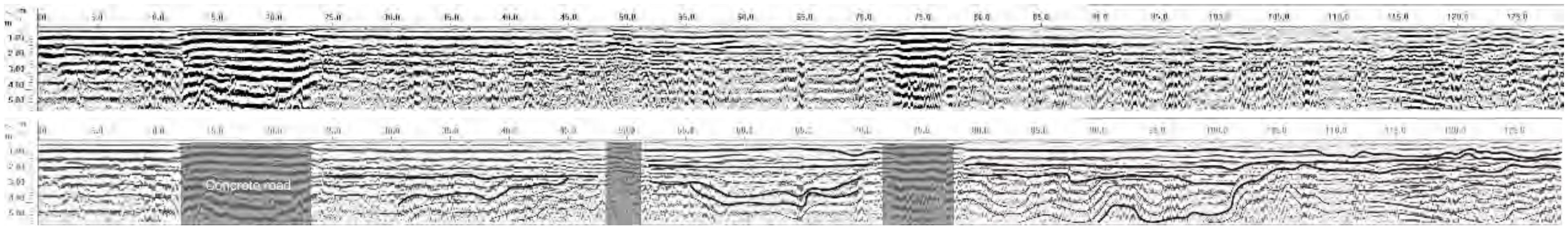

Figure 35. GPR raw data of Line 1.

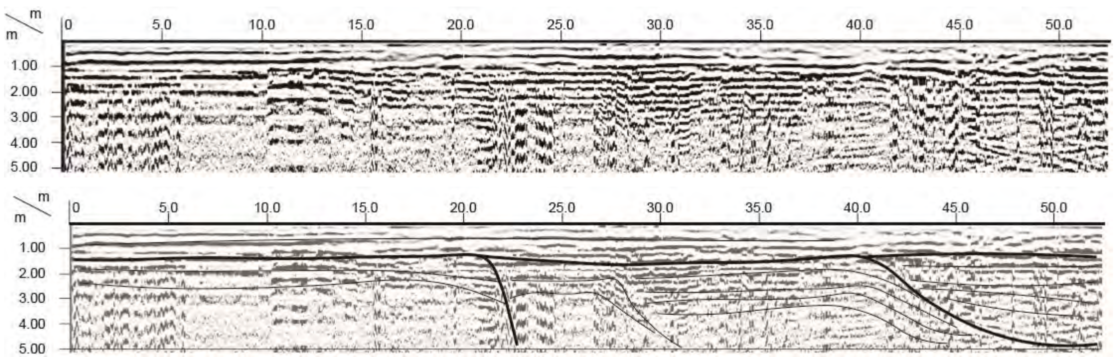

Figure 36. GPR raw data of Line 2.

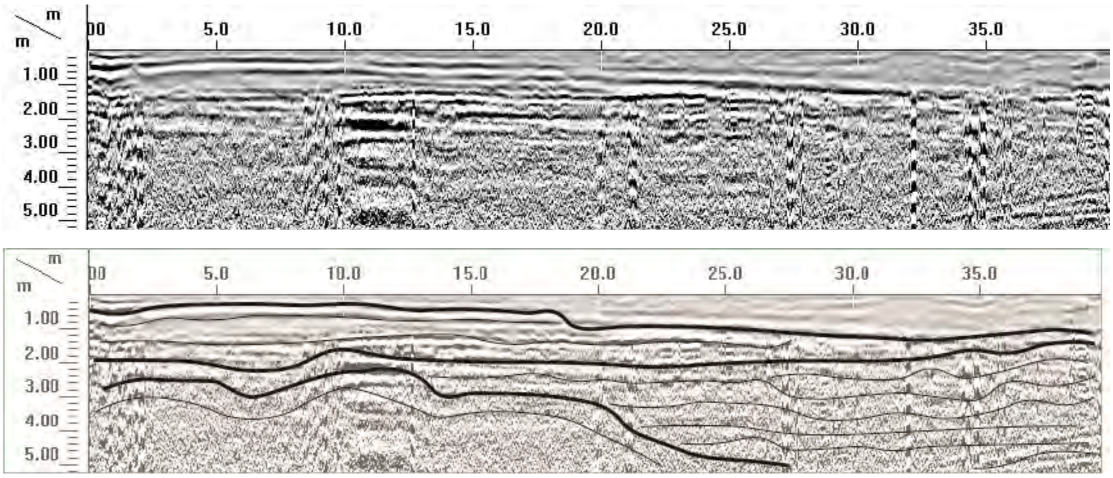

Figure 37. GPR raw data of Line 3.

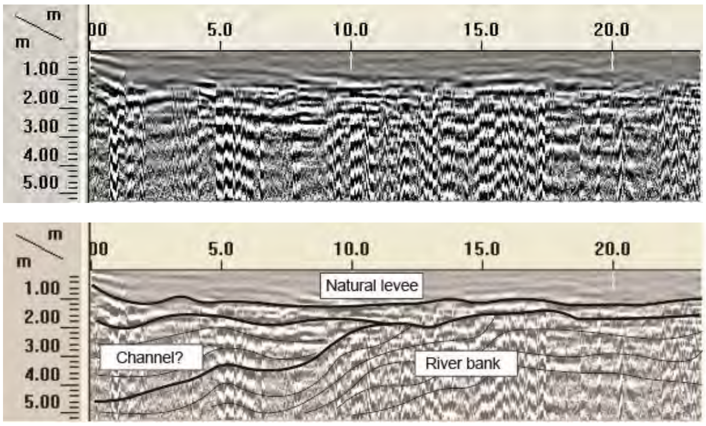

Figure 38. GPR raw data of Line 4.