HYDROMORPHOLOGICAL CHANGES OF CHI RIVER, MUEANG DISTRICT, KHON KAEN PROVINCE

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Geology
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การเปลี่ยนแปลงอุทกธรณีสัณฐานของแม่น้ำชีในพื้นที่อำเภอเมือง จังหวัดขอนแก่น

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Field of Study	Geology
Thesis Advisor	Professor MONTRI CHOOWONG, Ph.D.

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ภวัต วัฒนจารีกูล : การเปลี่ยนแปลงอุทกธรณีสัณฐานของแม่น้ำชีในพื้นที่อำเภอเมือง จังหวัดขอนแก่น. (HYDROMORPHOLOGICAL CHANGES OF CHI RIVER, MUEANG DISTRICT, KHON KAEN PROVINCE) อ.ที่ปรึกษาหลัก : ศ. ดร.มนตรี ชูวงษ์

วัตถุประสงค์ของวิทยานิพนธ์ฉบับนี้คือการประเมินสภาพอุทกธรณีสัณฐานของแม่น้ำชีในพื้นที่อำเภอเมืองจังหวัดขอนแก่น ใน 5 ช่วงเวลาที่แตกต่างกันได้แก่ พ.ศ. 2495 พ.ศ. 2531 พ.ศ. 2535 พ.ศ. 2549 และ พ.ศ. 2563 และวิเคราะห์ค่าดัชนีสัณฐานวิทยาที่เกี่ยวข้องซึ่งได้แก่ ค่าดัชนีความโค้งของแม่น้ำ ค่าความกว้างของแม่น้ำ อัตราการ เปลี่ยนแปลงความกว้างของแม่น้ำ อัตราการย้ายตำแหน่ง เพื่ออธิบายสภาพธรณีสัณฐานของแม่น้ำ นอกจากนี้วิทยานิพนธ์ฉบับนี้ยังได้นำข้อมูลที่ได้จากการออกภาคสนาม และข้อมูลภาพตัดขวางของลำธารมาวิเคราะห์ร่วมด้วย สำหรับพื้นที่ศึกษาครอบคลุมความยาวแม่น้ำ 67 กิโลเมตร และบริเวณดังกล่าวเป็นพื้นที่ที่ได้รับความเสียหายจากอุทกภัยบ่อยครั้ง ส่วนการประเมินสภาพอุทกธรณีสัณฐานนั้นจะใช้ดัชนีสัณฐานวิทยา (MQI) มาประเมินระดับการเปลี่ยนแปลงอุทกธรณีสัณฐานในรูปแบบระดับคะแนนสัมพัทธ์ตั้งแต่ 0 จนไปถึง 1 โดยหากคะแนนสัมพัทธ์เท่ากับ 1 แปลว่าพื้นที่ดังกล่าวไม่มีการเปลี่ยนแปลงสภาพอุทกธรณีสัณฐาน แต่ในทางกลับกันหากคะแนนสัมพัทธ์เท่ากับ 0 แปลว่าพื้นที่ดังกล่าวมีระดับการเปลี่ยนแปลงอุทกธรณีสัณฐานมากที่สุด ซึ่งจากผลการศึกษาพบว่าอัตราการย้ายตำแหน่งของแม่น้ำชีตามธรรมชาติมีค่าเฉลี่ยอยู่ที่ 0.725 เมตรต่อปี ส่วนค่าดัชนีสัณฐานวิทยาพบว่ามีค่าระหว่าง 0.84 ถึง 0.63 ซึ่งบ่งชี้ว่าพื้นที่ศึกษามีการเปลี่ยนแปลงสภาพอุทกธรณีสัณฐานอุทกธรณีสัณฐานเล็กน้อยไปถึงปานกลาง แต่อย่างไรก็ตามพบว่าค่าดัชนีธรณีสัณฐานตัวอื่นมีการเปลี่ยนแปลงอย่างมีนัยยะสำคัญ โดยพบว่าบริเวณที่มีการดำเนินการของบ่อทรายมีอัตราการเปลี่ยนแปลงค่าความกว้างของแม่น้ำอยู่ที่ 11.08 เมตรต่อปี สำหรับบริเวณที่เขื่อนชลประทานพาดผ่านพบว่ามีอัตราการย้ายตำแหน่งสูงสุดนั้นมากกว่า 90 เมตรต่อปี ในช่วงดำเนินการก่อสร้างเขื่อน (ระหว่าง พ.ศ. 2531 ถึง พ.ศ. 2535) นอกจากนี้ยังพบว่าค่าความโค้งของแม่น้ำลดลงจาก 1.53 (พ.ศ. 2495) เหลือเพียง 1.02 (พ.ศ. 2563) ซึ่งเป็นการบ่งชี้ให้เห็นว่าการก่อสร้างเขื่อนส่งผลต่อทิศทางการไหลของแม่น้ำ และสภาพธรณีสัณฐานของแม่น้ำ นอกจากนี้ยังพบว่าบริเวณที่มีการเปลี่ยนแปลงค่าดัชนีธรณีสัณฐานที่สูงมักเป็นบริเวณที่ระดับถูกรบกวนจากสิ่งปลูกสร้างจากมนุษย์สูง (ค่า MQI ต่ำ) ซึ่งบ่งชี้ให้เห็นว่าสิ่งปลูกสร้างในพื้นที่ศึกษามีผลกระทบต่อการเปลี่ยนแปลงสภาพธรณีสัณฐานสูงกว่าที่เกิดขึ้นเองตามธรรมชาติ สำหรับการวิเคราะห์การเปลี่ยนแปลง ค่าดัชนีสัณฐานวิทยา (MQI) และดัชนีธรณีสัณฐานที่เกี่ยวข้องในพื้นที่ศึกษาบ่งชี้ให้เห็นว่างานวิจัยด้านอุทกธรณีสัณฐานสามารถนำไปใช้ประโยชน์ในการวางแผนการจัดการแม่น้ำได้ไม่ว่าจะเป็นการทำนาย และป้องกันเหตุการณ์อุทกภัยในอนาคต รวม

สาขาวิชา	ธรณีวิทยา	ลายมือชื่อนิสิต ....
ปีการศึกษา	2563	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

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Pawat Wattanachareekul : HYDROMORPHOLOGICAL CHANGES OF CHI RIVER, MUEANG DISTRICT, KHON KAEN PROVINCE. Advisor: Prof. MONTRI CHOOWONG, Ph.D.

This thesis focuses on the analysis of hydrology coupled with geomorphology for river management such as flood mitigation and river restoration. Morphological Quality Index (MQI) is used for assessing hydro-morphological conditions from part of the Chi River (67 km long) at Khon Kaen province, a major river in north-eastern Thailand. This study area has been suffering from unexpected and repeated flooding. MQI is applied to evaluate the degree of hydro-morphological alteration in terms of relative scores (from 0 to 1). Basically, in case that MQI score equals 1, it means the area has no any alteration. On the other hand, if MQI score equals 0, the area has maximum alteration. The objective aimed at evaluating hydro-morphological conditions from 5 periods: 1952, 1988,1992, 2006, and 2020. The other relative geomorphic indexes were used to describe river planform including sinuosity index (SI), widening rate of channel width and migration rate of the river. Field survey and channel profiles were conducted. As a result, the natural migration rate of Chi River was calculated as average 0.725 m/year. MQI in the study area ranges from 0.84 to 0.63 indicating that the area owns a degree of alteration from minor to moderate alteration. However, the other geomorphic indexes from river segments shows high alteration. The maximum widening rate is 11.08 m/year in the area where sand mining in the river was observed. In place where a dam across the Chi River was constructed (1988-1992), maximum migration rate was up to 90 m/year and SI value had changed from 1.53 (in 1952) to 1.02 (in 2020). This indicates that the construction of dam has changed river direction and river planform. High geomorphic index alteration will correspond with many areas that were altered by artificial construction (low score of MQI). It suggests that artificial construction in the study area has more impact on river alteration than a natural process. The analysis in change of MQI

Field of Study:	Geology	Student's Signature ....
Academic Year:	2020	Advisor's Signature ....

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Chapter1: Introduction

1.1 Background

This study focused on the analysis in hydromorphological changes of the Chi River in Mueang district, Khon Kaen province, and the adjacent area. The hydromorphology represents a portmanteau word of "Hydrology" and "Geomorphology that is used for describing the interaction between hydrology, geomorphology, and river process (Vaughan et al., 2009). Hydromorphology considers river flow, river depth, river width, structure and substrate of the river bed, and floodplain structure. The hydromorphological condition affects the river's ecological status, such as the longitudinal connection of river effects to aquatic animal's migration in the breeding season. Moreover, hydromorphological degradation is one of the significant factors that cause poor ecological status in European rivers (Fehér et al., 2012).

It has many methods for assessing hydromorphological conditions depending on the study area's scale and purpose. The Morphological Quality Index (MQI) was applied to this work because it considers both rivers and areas affected by rivers. The MQI is applied to evaluate the degree of hydro-morphological alteration in terms of relative scores (from 0 to 1). Basically, in case the MQI score equals 1, it means the area has no any alteration. On the other hand, if the MQI score equals 0, the area has maximum alteration.

The Chi river is one of the main rivers in Khorat Plateau, Northeast of Thailand with more than 700 kilometers long. The Chi rises in the Phetchabun mountains then runs east through the central of northeast Thailand provinces: Chaiyaphum, Khon Kaen, and Maha Sarakham, then turns south in Roi Et, runs through Yasothon and joins the Mun in the Kanthararom district of Srisaket Province (Kuntiyawichai, Schultz, Uhlenbrook, & Suryadi, 2008). In rainy seasons during from May to October, there are often flash floods in the floodplain of the Chi River basin. The river was an 18th-century migration route for the Khorat Plateau's re-peopling by ethnic Lao people from the left (east) bank of the Mekong resettling on the right bank (Keyes, 1976).

Khon Kaen province, one of the major provinces of the northeastern Thailand, is a sloped area that dips from west to east and south. The geography of Khon Kaen is composed of the mountain area, hill area, and floodplain area. Mountain area can be divided into two types: Mesa topography belonging to the Khorat Group and karst topography belongs to the Saraburi Group (limestone). The hill area is composed of colluvial deposits, terrace deposits, and aeolian deposits. Floodplain area shows meandering river, sand bar, levee, meander scar. Khon Kaen itself is bounded in the north by Phetchabun, Loei, Nong Bua Lamphu and Udonthani, south by Nakhon Ratchasima and Buriram, in the west by Chaiyaphum and in the east by Maha Sarakham and Kalasin. Khon Kaen Province is far approximately 450 Km from Bangkok.

The study area covers part of the Chi River in Mueang district, Khon Kaen province, and the adjacent area (some parts of Kosum Phisai district, Maha Sarakham province) that lengths 67 kilometers. The study area has significant construction that is an irrigation dam constructed in 1988 and was operated in 1992. According to previous studies, dam affects downstream's sediment supply and downstream's channel geometry.

1.2 Objective

The prime objective of this research is as follows:

1. Assessing level of hydromorphological changing in chi river and riparian zone of chi river in Mueang district, Khon Kaen province and adjacent area by Morphological Quality Index (MQI)

2. Creating a geomorphological map of the chi river and riparian zone of chi river in Mueang district, Khon Kaen province, for analyzing the morphological changing pattern.

3. Describing River planform of chi river in Mueang district, Khon Kaen province in 5 different periods: 1952, 1988, 1992, 2006 and 2020 by a geomorphic index such as Sinousity Index (SI), Migration rate.

1.3 Scope

This research will mainly be concerned with the study of hydromorphological changing levels in the Chi River and riparian zone of the chi river in Mueang district, Khon Kaen province, and adjacent area evaluated by the Morphological Quality Index (MQI).The hydromorphological changes will be assessed by river continuity, channel pattern, cross-section configuration, bed structure and substrate, and vegetation in the riparian corridor (Rinaldi, Surian, Comiti, & Bussettini, 2013) . Additionally, Geomorphic maps and other geomorphic indexes, including the Sinuosity Index (SI), the Migration rate of the river, widening rate, and degree of asymmetry channel, are interpreted with hydromorphological changing level.

This research's output is expected to comprehend of hydromorphological changing of the Chi river that contributes to illustrate geomorphology, hydrology, and river process of chi river in Muaeng Khon Kaen Province. The thesis will describe the relationship between the level of disturbance from artificial elements and Geomorphic index alteration.

1.4 The Study Area

This section describes the environmental setting of Mueang district, Khon Kaen province and adjacent area (Some area of Kosum Phisai district, Maha Sarakham province). The description will start with general topography, geology, climate conditions and historical flood. Figure 1 shows the boundary of study area.

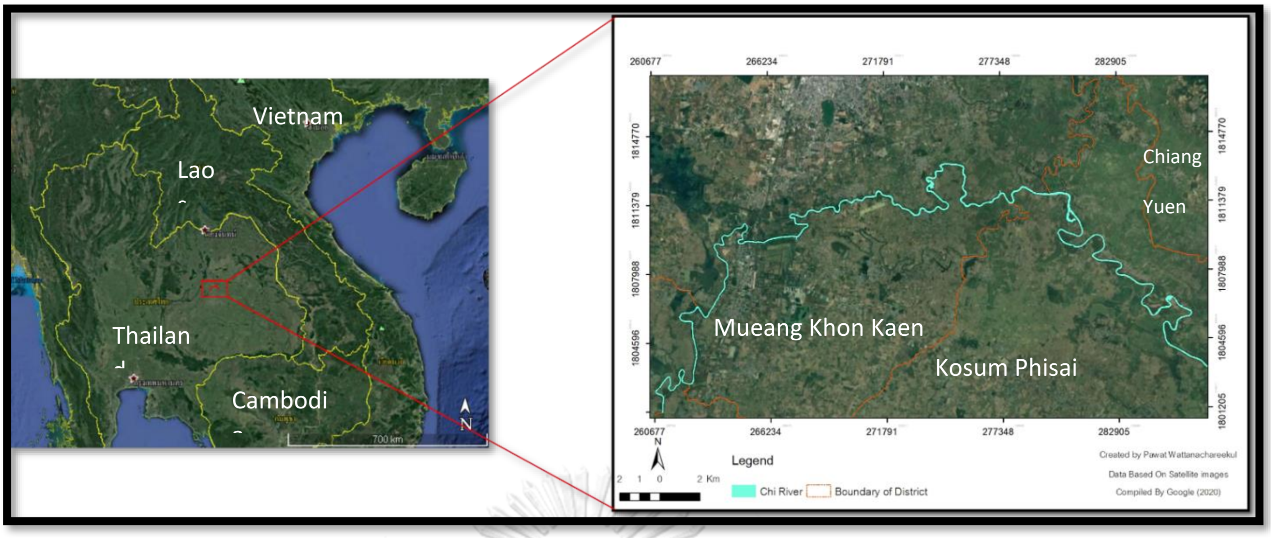

Figure 1 Study area: Chi river and riparian zone of chi river in mueang district, Khon Kaen province and adjacent.

1.4.1 Topography

Mueang district, Khon Kaen province, and adjacent area is the low-lying plain of the Chi river in Khorat plateau, Northeast Thailand. The study area appears in the reference topographic map at a scale of 1:50,000 series L7018 WGS 84 number 5541 I and 5641 IV.

1.4.2 Geology

According to geological map from DMR (2008a) and DMR (2008b), Geology of Mueang district, Khon Kaen province and adjacent area (Figure 2) consists of Cretaceous sedimentary rock and Quaternary sediment.

1.4.2.1 Cretaceous sedimentary rock

In study area has two cretaceous formations of Khorat group: Mahasarakham Formation and Phu Tok Formation.

1.4.2.1.1 Mahasarakham Formation

Mahasarakham Formation is a rock salt layer with a typical section as groundwater well at Mahasarakham province (Gardner, 1967). This formation cannot be found outcrop because it is covered by Quaternary sediments (Meesook, 2000). The thickness of the Mahasarakham formation ranges from 610-1,000 meters. The Maha Sarakham Formation can be divided into six members (Suwanich, 1985).The oldest member, the lower rock salt member, is the thickest rock salt layer. Moreover, this member found potash. The second oldest member, Lower mudstone, consists of mudstone, claystone, Reddish brown, massive, greenish mottle, carnallite, and halite veinlet sequence in ascending order. The third oldest member, Middle rock salt, consists of halite, gypsum, anhydrite. The fourth oldest member, Middle mudstone, consists of mudstone and claystone. This member does not have a carnallite veinlet. The second youngest member, Upper rock salt, does not have potash. The youngest member is an upper sedimentary rock. (Meesook, 2000) interpreted that the Mahasarakham formation was deposited in saline water in lakes and ponds in arid paleoclimate. The Mahasarakham formation age was given as Cenomanian (Lower Upper Cretaceous (Sattayarak, Srigulawong, & Patarametha, 1991).

1.4.2.1.2 Phu Tok Formation

Phu Tok Formation is thick massive reddish sandstone, claystone, and siltstone composed of three members (Meesook, 2000). The oldest member is Na Wah member, a thick bed to massive reddish-brown mudstone and claystone. The second oldest member, Kham Ta Kla, consists of cross-bedding sandstone, cross-bedding mudstone, and cross-bedding siltstone. The youngest member, Phu Tok Noi member is mega cross-bedding reddish sandstone. Meesook (2000) interpreted that Phu Tok formation was deposited in both occasional meandering rivers and semi-arid winds to arid paleoclimate. The Age was given Age is given as Upper Cretaceous to Lower Tertiary (Meesook, 2000).

1.4.2.2 Quaternary Sediment

In study area has three sedimentary units. First, alluvial deposit unit consist of sediment particle size from sand to clay. Second, alluvial deposit with saline soil unit is similar with alluvial deposit unit but sedimentary in this unit contaminates with saline soil. Third, Low terrace deposit is consisted of gravel bed and laterite.

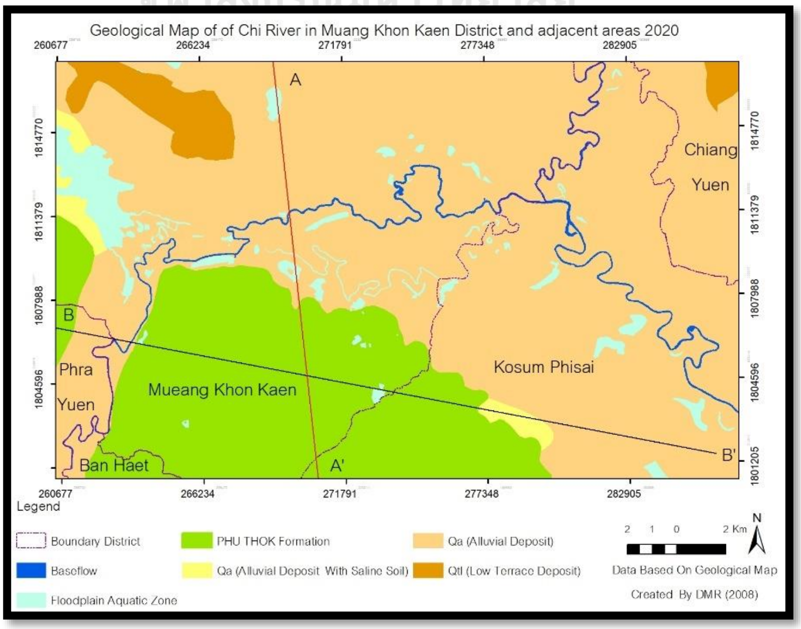

Figure 2 Geological Map of Study area: Mueang district, Khon Kaen province and adjacent area. (Modified from DMR (2008)).

1.4.2.3 Cross-Sectional line

According to the geological map (Figure 2), it has two cross-sectional lines: Line A-A' and Line B-B'. the Line A-A' orientates in North-South of study area While Line B-B' orientates in Northwest-Southeast direction.

1.4.2.3.1 Line A-A'

The Line A-A' crosses the central of study area in North-South direction. It can be seen from Figure 3 that Chi river flow on sedimentary alluvial deposit unit. This unit overlain on Ta Kla member, Phu Tok Formation and Mahasarakham Formation. In addition, this section has a fault plane. It implies that the chi river developed on fault plane.

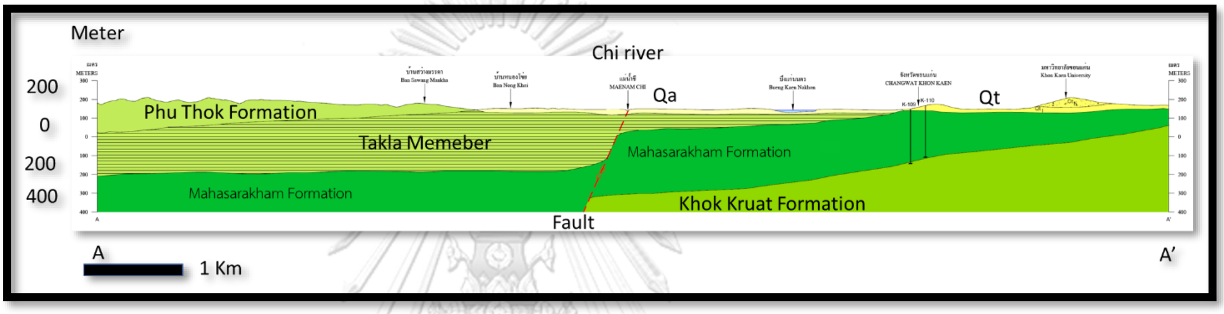

Figure 3 Cross-sectional line A-A' : Quaternary sediments overlain Phu Tok Formation (DMR, 2008).

1.4.2.3.2 Line B-B'

The Line B-B' crosses the Chi river segment that has channel planform as straight. It can be seen from Figure 4 that Chi river flows on sedimentary alluvial deposit unit that overlain on salt dome of Mahasarakham Formation. Thus, it may be assumed that the salt dome of the Mahasarakham Formation is structural control on river planform.

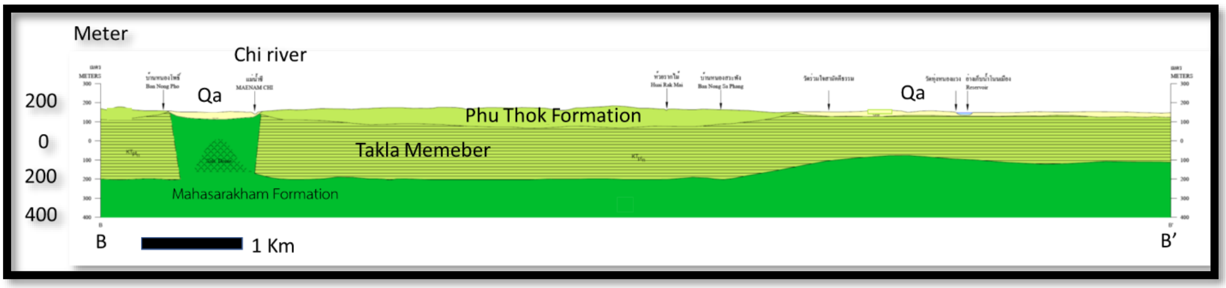

Figure 4 Cross-sectional line B-B' : Quaternary sediments overlain Salt dome of Mahasarakham Formation (DMR, 2008).

1.5 Climate

The climate of Khon Kaen is a savanna that can be classified in Köppen Climate Classification as AW. The average temperature for the year in Khon Kaen is 81.0 °F (27.2 °C). The warmest month, on average, is April, with an average temperature of 87.0°F (30.6 °C). The coolest month on average in January, with an average temperature of 72.0 °F (22.2 °C). For precipitation, the average amount of precipitation for the year in Khon Kaen is 49.6" (1259.8 mm). The month with the most precipitation on average is September with 11.0" (279.4 mm) of precipitation. The month with the least precipitation on average is December, with an average of 0.1" (2.5 mm).

The season in Khon Kaen can be classified in three seasons: summer, rainy and winter. The hot season ranges from February to April. The rainy season ranges from May to October. While, the cool season ranges from November to January.

1.6 Runoff data

The graph of average runoff data from E.9.1.A Station (RID station) in each month from 2005 to 2020 shows in figure 5. According to the graph, Y-axis is the average runoff data that was measured in cubic metre per sec while X-axis is month. The average run off data ranges from 77.07 cubic metre per sec (in April) to 1241.2 cubic metre per sec (in October). It can be seen that period from January to April has low runoff data while the period from September to November has high runoff data.

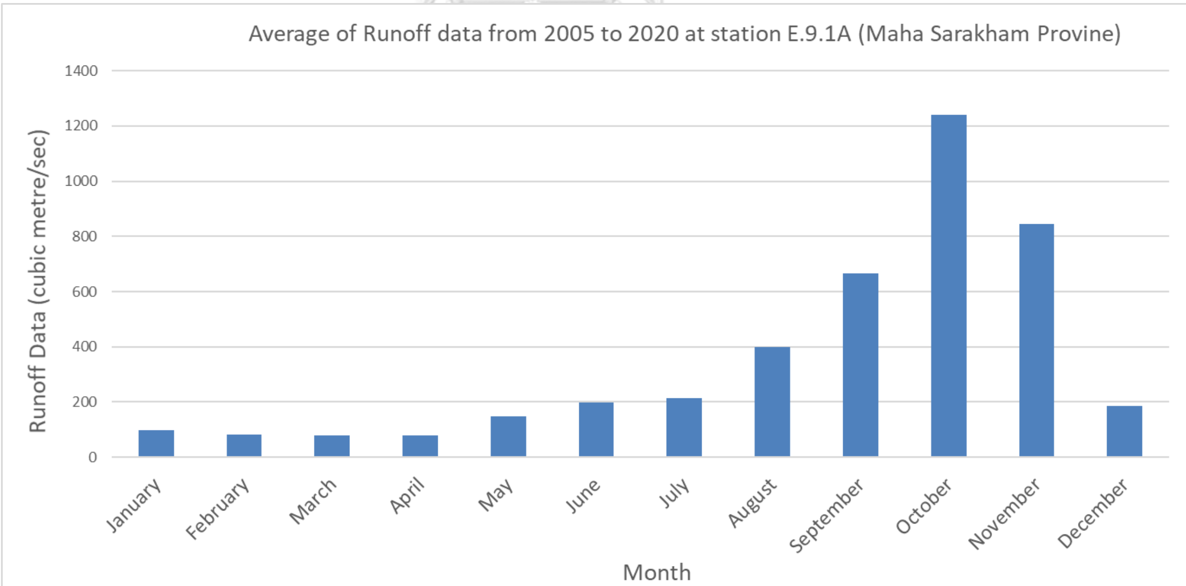

Figure 5 Average of Runoff data from 2005 to 2020 at E.9.1.A station (Maha Sarakham Province).

1.7 Historical Flood

The flood frequency from GISTDA (Figure 6) shows that the study area had been affected by flood average 2-4 times from 2005 to 2015. Thus, it can be concluded that the study area is a repeated flood area.

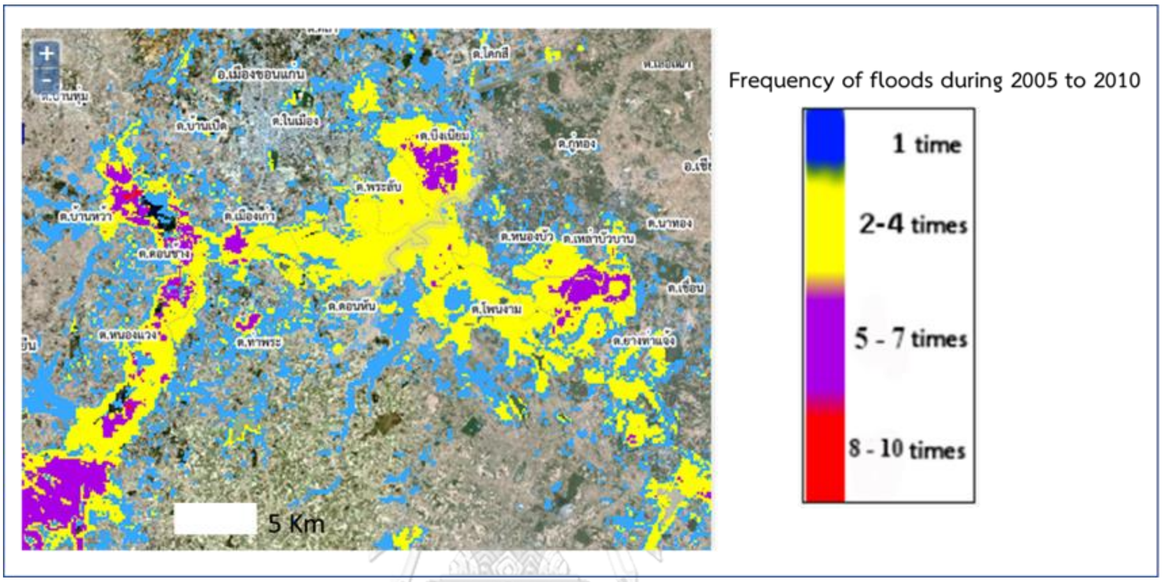

Figure 6 Frequency of flood during 2005 to 2010 map of mueang district, Khon Kaen province and adjacent area (Gistda).

Chapter2: Literature Review

In literature review section, the previous studies relating to this thesis will be described, for example, river geomorphic index, river classification, hydro morphological assessment, channel asymmetry and geomorphological effect on downstream of dam.

2.1 River geomorphic index

2.1.1 Sinuosity Index (SI)

Sinuosity Index (SI) is defined as the ratio between the channel length to down valley length (Leopold & Wolman, 1957; Mueller, 1968) (Figure 7). Sinuosity Index (SI) is usually used for characterized the intensity of meandering of the river and described river pattern (Lagasse, Zevenbergen, Spitz, & Thorne, 2004).Thus, SI implies river behavior because SI value can be altered by the river, such next cut off or chute cut off reduce SI. Moreover, Z. Li, Yu, Brierley, Wang, and Jia (2017) found that the lateral migration rate of the Tarim river does not only depend on local flow-sediment but also SI.

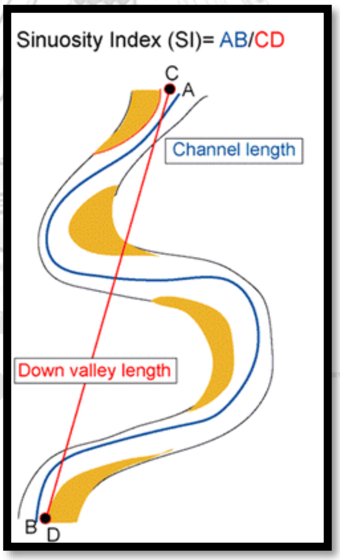

Figure 7 The detail of sinuosity index (Nimnate, Choowong, Thitimakorn, & Hisada, 2017).

2.1.2 Braiding index (BI)

Braided is the term that is recognized as multiple channels of rivers that were separated by emergent sediment or unstable island. For measuring the degree of braiding, it has three systems for measuring: Bar indices that based on the length of the mid-channel bar.

Channel length calculates the total sinuosity index and Count index that bases on the number of channels. Egozi and Ashmore (2008) suggested that the count index is preferred because it is not sensitive to variations in channel sinuosity and orientation. Moreover, the Count index has the smallest coefficients of variation and can be measured very quickly and reliably even from oblique photographs of reach. Therefore, the definition of braiding index that follows the definition from Egozi and Ashmore (2008) is the number of active channels at baseflow separated by emergent sediment. However, the calculation should be calculated at least ten different cross-sections because the braiding index depends on the water discharge flowing in the river, such some channels will merge or disappear in the dry season. For application, the braiding indices have been used in correlating braided channel patterns with the flow, stream power, sediment transport, morphology, and vegetation parameters.

2.1.3 Anabranching index (AI)

Anabranching rivers are recognized as multiple channels of rivers that were separated by vegetated islands or stable islands. The term of anabranching has resulted in two terms. The first term is anabranching that is used for describing multiple channels of rivers that have higher-energy and coarse-grained (North, Nanson, & Fagan, 2007).The second term is anastomosing that is used for describing river pattern that was associated with mostly fine-grained or organic sedimentation (Smith, 1983). However, either 'anabranching' or'anastomosing' isn't applied as the term for 'braided' (Nanson, 2013). For describing anabranching, Nanson (2013) created an index as the term of Anabranching index that calculated from the number of active channels at baseflow separated by vegetated islands. The calculation should be calculated at least from 10 different cross-sections.

2.1.4 Confinement

2.1.4.1 Definitions of Confinement

Confinement is a primary control river behavior that describes the degree to which bounding inactive floodplain features (such as hillslopes, alluvial fans, glacial moraines, and river terraces) limit the lateral extent of the valley floor and the floodplain along a rive (N. David, Buffington, Parkes, Wenger, & Goode, 2014).For application, Valley confinement is used to classify river patterns and estimate sediment flux (Fryirs, Wheaton, & Brierley, 2016).

2.1.4.2 Confinement types

Analyzing confinement types uses two parameters: Confinement degree and Confinement index. The first parameter, Confinement degree (CD), evaluates the lateral confinement in longitudinal valley direction that equals to the percentage of river length, banks both sides, that was abutted by inactive floodplain area such as hill, terrace (Brierley & Fryirs, 2005).The second parameter, Confinement index (CI), evaluates the ratio between floodplain width (including the channel) and channel width. This index is inversely proportional to confinement (Rinaldi et al., 2013). The minimum of the confinement index is 1 that indicates that this area does not have a floodplain. For the result, Rinaldi et al. (2013) classified confinement into 3 types: confined, partly confined, and unconfined (Figure 8). The first type, confined, means this section has a confinement degree more than 90 % in any case or confinement degree between 10 to 90% and a confinement index less than 1.5. The second type, partly confined means this section has a confinement degree between 10 to 90% and confinement index more than 1.5 or confinement degree less than 10 %, and confinement index less than 5 (for single thread). The last type, unconfined means this section has a confinement degree less than 10 % and a confinement index less than 5 (for a single thread).

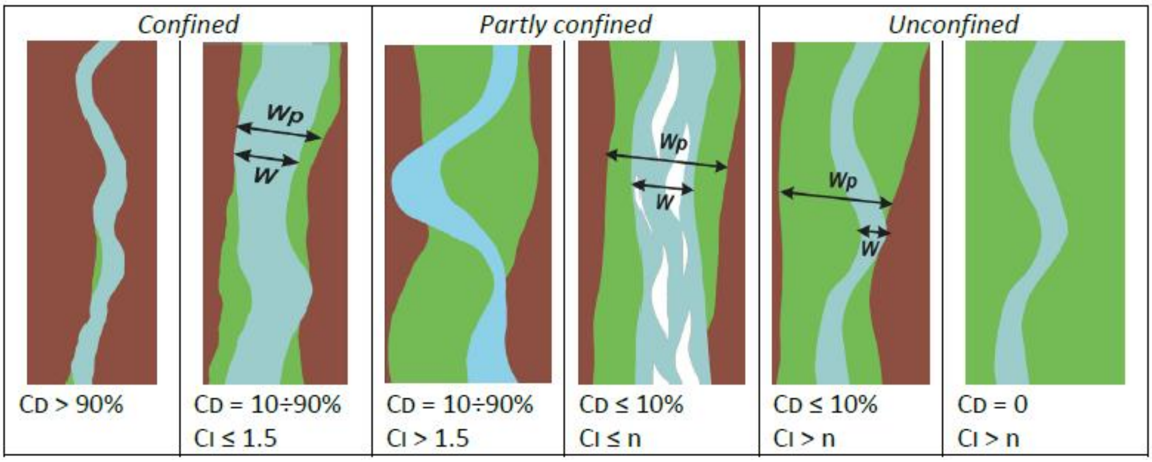

Figure 8 Figure shows the details of confinement type (Rinaldi et al., 2016).

2.1.5 Channel Width

Channel width means the width of the main channel that is measured from one side to another side of the channel. Channel width can be used for several investigations such Hooke (2007) used average channel width from several locations to investigate channel planform change, or Thayer (2017) used channel width to calculate specific stream power. Moreover, some hydrological models use channel width to calculate river power or shear stress (Finnegan, Roe, Montgomery, & Hallet, 2005).

2.1.6 Migration Rate

River migration is the geomorphological process that means the lateral migration of a river channel across its floodplain. This process is reflecting in the cutoff, erosion, and point bar deposition process (Bierman & Montgomery, 2014). Migration rate reveals the rate of lateral movement of the river that can be used for finding the trend of river movement and describing channel geometry. The lateral migration rate depends on many factors: the resistance of convex bank against erosion, the continuity and magnitude of flow, radius of curvature channel, and the flow capacity for sediment transport (Esfandiary & Rahimi, 2019). For measuring migration rate, it can be measured by remote-sensing data and GIS techniques (Nicoll & Hickin, 2010).

2.2 River Classification

The river can be classified into several types from its geometry and the processes operating within its reach (Raj & Bhandari, 2004).Traditionally, the river can be classified, by sinuosity index (SI), into three types: straight, meandering, and braiding types (Leopold & Wolman, 1957).But Gurnell et al. (2014) considered more factors: thread of channels, Braided index, and anabranching index. For partly confined and unconfined conditions, Gurnell et al. (2014) classified rivers into 6 types: Straight, Sinuous, Meandering, Wandering, Braided, and Anabranching (Figure 9). The details of each river type are shown in table 1.

River classification can be divided into two conditions based on confinement type: confine condition and partly confined and unconfined condition.

1. Confined condition: This condition can be divided into three broad categories based on the number of threads: single thread, transitional zone, and multiple threads. However, a single thread is the most common type in this condition. For single thread confined, sinuosity index is not meaningful as it is determined by the valley rather than the channel planform. Therefore, single-thread confined channels are not further sub-divided at this stage because it is not possible to make accurate distinctions based on other characteristics, particularly the bed configuration, from remotely sensed sources. For transitional zone and multiple threads in confined condition, it uses the same criteria with partly confined and unconfined condition.

In other case, river can be classification in three groups that based on number of threads: Single thread, Transitional zone and Multiple thread.

1.1 Single thread: It means river has only one channel that can be classified into three types base on degree of sinuous: Straight, Sinuous and Meandering.

1.1.1 Straight river has sinuosity index value less than 1.05 at bank full condition. In nature, straight river is usually found as short river although long straight rivers seldom occur in nature. In dry season, alluvial bars exist on either side of the stream.

1.1.2 Sinuous river has sinuosity index value between 1.05 to 1.5 at bank full condition.

1.1.3 Meandering river has sinuosity index value more than 1.5 at bank full condition. The meandering rivers are asymmetrical river because the deepest part of river is outer bend. The flow at outer bend has faster than inner bend. Thus, sediment at outer bend is eroded and deposits at outer bend.

1.2 Transitional zone: Transitional zone shows intermediate characteristics between single thread and multiple threads. That means some area of the river has only one channel, but another area of the river has multiple channels. Moreover, the river width of the transitional zone is wider than a single thread. The transitional zone has one type of river that is called wandering.

1.2.1 Wandering river

Wandering river is a wide and depth channel that is occupied by emergent sediment or active bar but Braiding index value and anabranching index are lower than 1.5.

1.3 Multi threads: Multi threads mean that river has more than one channel. It can be classified into two types: Braided and Anabranching.

1.3.1 Braided river

Braided river is wide and shallow river and divided to branches by emergent sediment. The braided river has braiding index more than 1.5

and anabranching index lower than 1.5 The braided river is unstable river because some emergent sediment will be disappeared in flooded season while some branch channel will be disappeared in low flow stage. However, main channel of braided river is stable.

1.3.2 Anabranching river

Anabranching rivers are recognized as multiple channels of rivers that were separated by vegetated island or stable island. Anabranching river has anabranching index more than 1.5. Anabranching river is more stable than braided river because vegetate island is not disappeared in bankfull stage and Brach channel is not disappeared in low flow stage.

Thread	Sinousity Index (Si)	Braiding Index (BI)	Anabranching Index (Ai)	Typology
Single	1 ≤ Si <1.05	1 ≤ Bi <1.5	1 ≤ Ai <1.5	Straight (ST)
	1.05 ≤ Si <1.5	1 ≤ Bi <1.5	1 ≤ Ai <1.5	Sinuous (S)
	Si ≥ 1.5	1 ≤ Bi <1.5	1 ≤ Ai <1.5	Meandering (M)
Transitional	Not applied	1 ≤ Bi <1.5	1 ≤ Ai <1.5	Wandering
Multiple	Not applied	Bi ≥ 1.5	1 ≤ Ai <1.5	Braided
	Not applied	1-1.5	Ai ≥ 1.5	Anabranching

Table 1 Table shows the details of river classification (Gurnell et al., 2014)

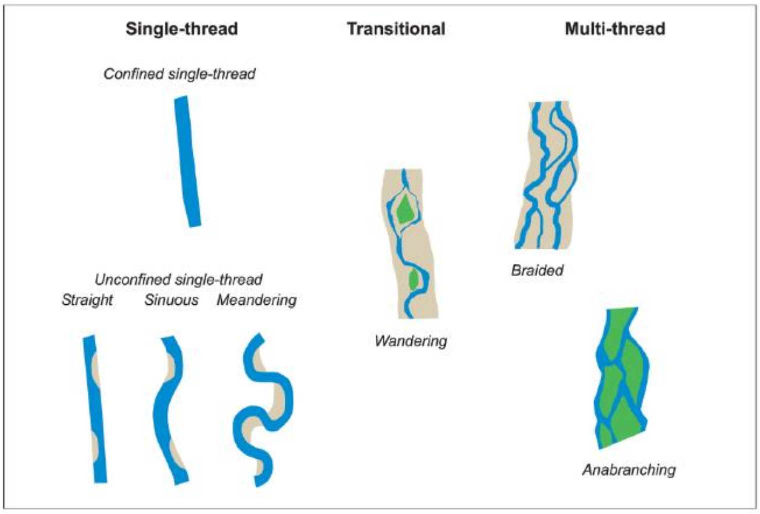

Figure 9 The classification of river (Gurnell et al., 2014).

2.3 Hydromorphological assessment

2.3.1 Types of hydromorphological assessment

Recently, hydromorphological assessment has been developed for applying with river management. It has many hydromorphological assessment methods with different countries, purposes, scales, and approaches. Hydromorphological assessment method had been categorized by B Belletti, Rinaldi, Buijse, Gurnell, and Mosselman (2015) into 4 categories: physical habitat assessment, riparian habitat assessment, morphological assessment, and flow regime alteration. The first method, physical habitat concerns only the physical properties of the water body of the river. The result from the physical habitat method can be applied in the ecological and biological study because this method concerns ecological and biological components. But this method has many limitations, such it can be applied to a small area. Moreover, this method consumes budget and time because this method interprets data only from field survey data. The next method, Riparian habitat assessment concerns an only area that has affected by a fluvial process such as a floodplain, meander scar. The limitation of this method is riparian zone has many factors that can affect such as a distribution from humans, vegetation, climate. Thus, if Assessor does not concern about all factors, result will be wrong. Next method, the Morphological assessment that is applied in reach scale concerns both of water body of the river and riparian zone. This method interprets data from remote sensing data. This method reduces time and budget. But this method lacks some information such as vertical continuity of river, biological and ecological data. The last method, flow regime alteration concerns river flow patterns and the trending of flow patterns under the assumption that the groundwater system is not alteration. Suppose the groundwater system alters from reference condition. The result will not be accurate. But this method has many strengths such a result can be applied on a large scale and can be predicted a flow alteration trend.

2.3.2 Delineation spatial scale unit for hydromorphological assessment

Hydromorphological assessment has many methods that are different in purposes, scales, and approaches. Thus, each method has appropriate spatial scales for investigation. González del Tánago, Gurnell, Belletti, and garcia de jalon (2015) summarized spatial scales that are used in hydromorphological assessment, from coarsest to finest scale, into 6 types: Catchment Scale, Landscape Scale or Physiographic Scale, Segment scale or Sector scale, Reach scale, Geomorphic Unit and Hydraulic Unit. The coarsest scale, catchment is an area of land that is drained by a river and its tributaries that can be defined boundary by topographic divided or watershed. The second coarsest scale, Landscape scale is portions of the catchment with similar morphological characteristics that can be defined boundary by geological and geomorphological characteristics. The third coarsest scale, segment scale is portions of landscape with similar confinement conditions that can be defined boundary by confinement degree and confinement index. The fourth coarsest scale, reach scale is portions of section scale that has similar in degree of artificial elements and morphology of river such as floodplain features. This scale is usually applied in river management such as restoration river. The second finest scale, geomorphic unit, is area similar in geomorphology. The finest scale, Hydraulic unit is the area with similar flow condition.

2.3.3 Geomorphic unit for hydrological assessment

Some geomorphic units in the river are a physical habitat for the aquatic animal. The method of geomorphic survey units for physical habitat has been developed since 1980, but it has two limitations. The first limitation, many methods fixed the spatial scale of the study area (Belleti et al., 2015). The second limitation, many methods produced maximum morphological diversity for all types of rivers. This was leading to the problem that the geomorphic unit was very complex. It was hard to categorize, therefore, Barbara Belletti et al. (2017) created geomorphic units survey and classification system (GUS) to solve this problem. The GUS method can use in multiple scales because it produces geomorphic unit that has been categorized by spatial setting and appeared feature in three spatial scale level: macro unit, unit, and sub-unit. The coarsest spatial scale, macro unit is a group similar in water, sediment, vegetation, and setting. The macro unit has 5 types: baseflow unit, emergent sediment, channel vegetation, riparian zone and floodplain aquatic (Figure 10). The first macro unit, base flow unit is the water body of the main and branch channel of the river. The second macro unit, emergent sediment is sediment that emerges without vegetation in the river channel. The third macro unit, channel vegetation, is emergent sediment that has been covered by a plant. The next macro unit, the riparian zone is the area that has been affected by a fluvial process such as Levee, floodplain, terrace. The last macro unit, floodplain aquatic is a water body that displays in flood plain area such as a lake. The second coarsest spatial scale unit is portions of the macro unit that have distinctive in term of morphological characteristics and significant size such as floodplain, island. The size of the unit is available that depends on the setting of unit. Table 2 shows the detail of each unit. The finest scale, sub-unit, is the small patch with fairly homogeneous characteristics in terms of vegetation, sediment, or flow conditions located in unit scale. The size of the sub-unit is smaller than unit.

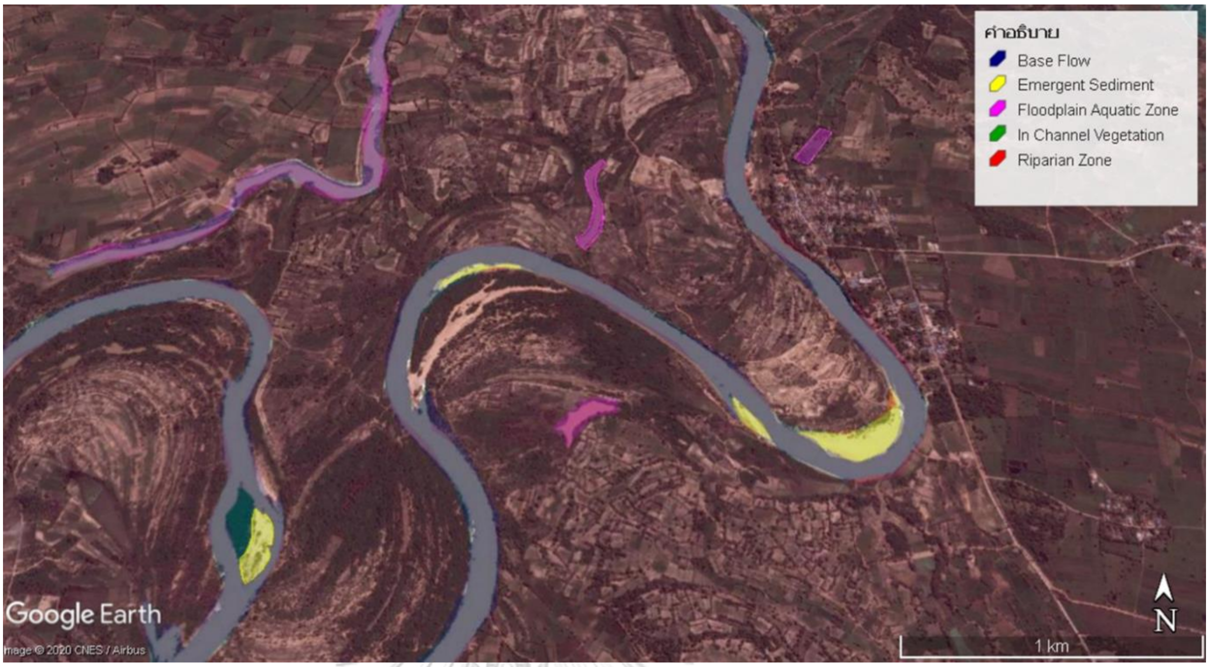

Figure 10 Classification of 5 macro units (Google Earth, 2015).

For analyzing, GUS analysis in terms of the geomorphological map has three levels: board level, basic level, and detailed level. The coarsest level, the board level corresponds to the delineation and a general characterization that shows the boundary of the macro unit. The board level is produced from the aerial photograph or satellite image by remote sensing and GIS technique. The second coarsest level, the basic level is complete delineation and the first level of characterization of all types of geomorphic units in terms of presence/absence, number, area, or length of macro-units. The board level is produced by data from remote sensing and GIS techniques and data from field surveys. Figure 11 shows the difference between the board level and the basic level. The finest level, the detailed level provides detailed information in terms of morphological, hydrological, vegetation, and sediment properties.

For the application, data that is produced from the GUS method can describe hydromorphological conditions. Moreover, it can make application in biology such as habitat of aquatic animals.

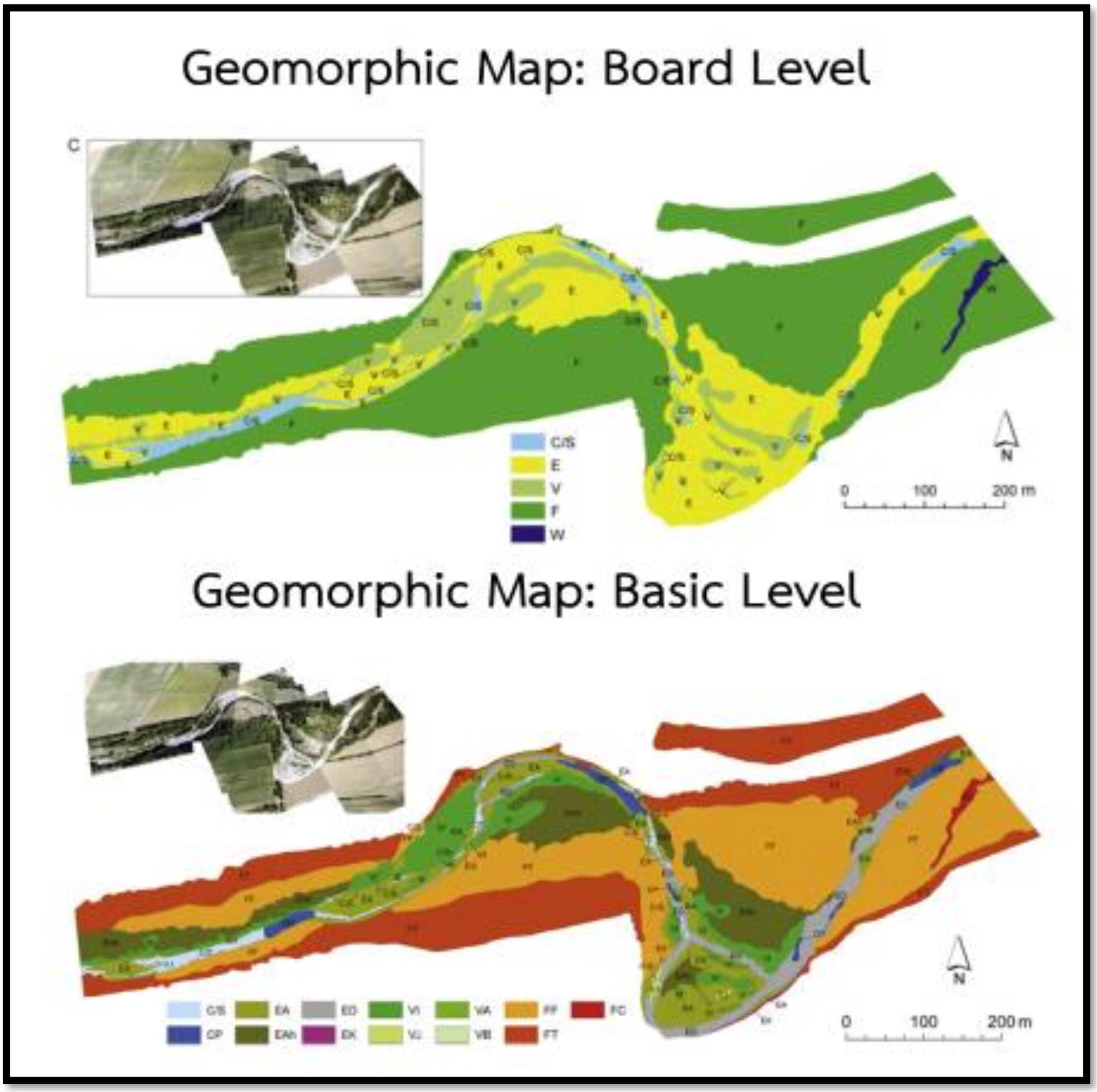

Figure 11 The characterization of board level map and basic level map (Belleti et al., 2017).

Macro Unit	Unit	Definition
Base flow unit	Main Channel	The main channel of river
	Secondary Channel	The branch river
Emergent Sediment	Bank Attached Bar	The sediment, which has grain size lower than sand, attaches at river bank.
	Mid Channel Bar	The sediment, which has grain size lower than sand, emerges in mid channel.
	Bank-attached high bar	The sediment, which has grain size more than gravel, attaches at river bank.
	Mid Channel high Bar	The sediment, which has grain size more than gravel, emerges in mid channel.
	Dry Channel	Channel has no water flow in dry season.
	Bed rock outcrops	Outcrops emerge in mid channel.
	River bank	River bank
Channel Vegetation	Island	Mid channel bar is covered by plant.
	Aquatic Vegetation	It has aquatic plant that grows in channel.
	Large wood jam	It has tree log that accumulates in channel.
	Vegetated bank	River bank is coved by plant.
	Bench (Berm)	Edge of river bank is covered by plant.
Riparian Zone	Modern Floodplain	Modern flat area of land next to a river.
	Recent Terrace	A step-like landform.
	Scarp	Area has been developed from floodplain to terrace.
	Levee	Levees are natural embankments.
	Overbank Deposit	Sediment deposits during overbank process.
	Ridge and Swale	Dunal area in floodplain
	Floodplain island	Floodplain in anabranch river system
	Terrace island	Terrace in anabranch river system
	Secondary Channel (Within)	Small stream does not connect to main channel.
Floodplain aquatic zone	Floodplain Lake	Surface water in floodplain
	Wetland	Area is flooded by water, either permanently or seasonally, where oxygen-free processes prevail.

Table 2 Table shows the details of sub unit (Belleti et al., 2017).

2.3.4 Morphological Quality Index (MQI)

Rinaldi et al. (2013) created the Morphological Quality Index (MQI) which was a morphological assessment method for reach scale. The MQI describes the degree of hydromorphological alteration and distribution of current condition from reference condition that means river at 50-100 years ago. The evaluation is based on a relative score system, score range 0 to 1, from 28 indicators which are defined to assess river continuity, channel pattern, cross-section configuration, bed structure and substrate, and vegetation in the riparian corridor. The 28 indicators that are shown in table 3 can be classified into 3 categories: Artificiality, channel adjustment, and geomorphic functionality. The first category, artificiality, evaluates the number of artificial elements and intervention processes such as bank protection. The second category, channel adjustment, evaluates the degree of alteration of channel river in three topics: width, depth, and channel pattern. The final category, geomorphic functionality evaluates whether or not the river process and morphological conditions are altered by artificial element and channel adjustment. Before evaluating, confinement condition must be found because some indexes use only in specific confinement condition. After evaluating, the next step is calculating Morphological Quality Index (MQI) score that is calculated as follows equation 2.1.

$$MQI = 1 - (Stot / S\ max) \quad \text{(Equation 2.1)}$$

Where Stot is the sum of the scores and Smax is the maximum score that could be reached when all appropriate indicators are in maximum alteration condition.

For MQI Sore, Score ranges from 0 to 1, leading to a divide to 5 morphological quality classes: 1. High class, score ranges from 1 to 0.85, 2. Good class, score ranges from 0.7 to 0.85, 3. Moderate class, score ranges from 0.5 to 0.7, 4. Poor class, sore ranges from 0.3 to 0.5, 5. Bad Class, score below 0.3. The high class means this study area doesn't have alteration and distribution, although the bad class means this study area has maximum alteration and distribution.

MQI has many strengths, such it can be applied in small scale, or it can be compared with the different area but MQI has some limitations such as it cannot be used in an area that has been affected by the coastal process, and MQI does not concern factor about groundwater systems that connect to river systems.

Artificiality	Geomorphological Functionality	Channel Adjustment
A1: Upstream alteration of flow A2: Upstream alteration of sediment A3: Alteration of flow (in reach) A4: Alteration sediment discharge A5: Crossing Structure A6: Bank Protection A7: Artificial Levees A8: Artificial change of river course A9: Other bed stabilization structures A10: Sediment removal A11: Wood removal A12: Vegetation management	F1: Longitudinal continuity in sediment and wood flux F2: presence of a modern floodplain F3: Hill Slop river corridor connectivity F4: Process of bank retreat F5: Presence of a potentially erodible corridor F6: Bed onfiguration F7: From and process typical channel pattern F8: Presence of typical of channel pattern F9: Variability of the cross-section F10: Structure of the channel bed F11: Presence of in-Channel large wood F12: Width of functional vegetation F13: Linear extension of functional vegetation	CA1: Adjustments in channel pattern CA2: Adjustments in channel width CA3: Bed-level Adjustment

Table 3 Table shows the details of each component (Rinaldi et al., 2013)

2.4 Analysis of Channel Asymmetry

The channel's cross-sectional shape depends on flow, sediment character, and composition of bed and bank material. About 90 % of the cross-sectional shape of the channel is asymmetry (Leopold & Wolman, 1957). Moreover, Majumder (2011) found that many cross-sectional shapes of the straight river are asymmetrical. The technique for measuring the degree of asymmetry has been developed since 1981. Knigthon (1981) created three indices for measuring the degree of asymmetry: A*, A1 and A2. A* is measuring the degree of asymmetry of river channel cross-sectional form that calculates from the other area differences in the area between the two parts of the channel and is defined as Equation 2.2. The range of A* is -1 to 1. If the channel is symmetrical, A* value is near 0. However, If the channel is in extreme symmetry, A* value is near -1 or 1.

$$A^* = (A\ left - A\ right) / Total\ Area \quad \text{(Equation 2.2)}$$

A1 index considers the degree of horizontal asymmetry that is defined as Equation 2.3. However, A2 index considers the degree of vertical asymmetry that is expressed as Equation 2.4. If A1 and A2 equal to 0, it means this cross-sectional shape is symmetrical. However, If A1 and A2 don’t look similar to 0, it means this cross-sectional isn’t symmetrical. In contrast, X is the horizontal distance from the centreline to the centroid of maximum depth.

$$A_1 = (2 * X * \text{maximum depth}) / \text{Area}$$ (Equation 2.3)

$$A_2 = (2 * X *(\text{Maximum depth} - \text{Depth at center line}) / \text{Area}$$ (Equation 2.4)

Das and Islam (2018) developed a new three index for measuring the degree of asymmetry from Knigthon (1981) called Aa, Aw and Awa. These indices are calculated from the difference between the median area line (Lm) and the centerline of the channel (Lc). The median line means a line that halves cross-sectional area, and the centerline of the channel means a line that halves the cross-sectional area's width. Figure 12 shows the Definition of parameters of an asymmetrical channel. Aa considers the difference in area asymmetry, although that is defined as Equation 2.5 Aw considers the difference in area asymmetry that is defined as Equation 2.6. Awa is a product from Aw and Aa that is expressed as Equation 2.7. While A’ is area between the median area line and the centerline of the channel and W’ is the horizontal distance between the median area line and the channel's centerline. In this measure, if the value of these indices is ‘0’, the channel is perfectly symmetrical and if it is 1, the channel is 100 % asymmetric in nature.

$$A_W = 2W' / \text{Total Width of cross-sectional}$$ (Equation 2.5)

(Equation 2.7)

$$A_a = 2A' / \text{Total Area of cross-sectional}$$

(Equation 2.6)

$$A_{wa} = Aa * Aw$$

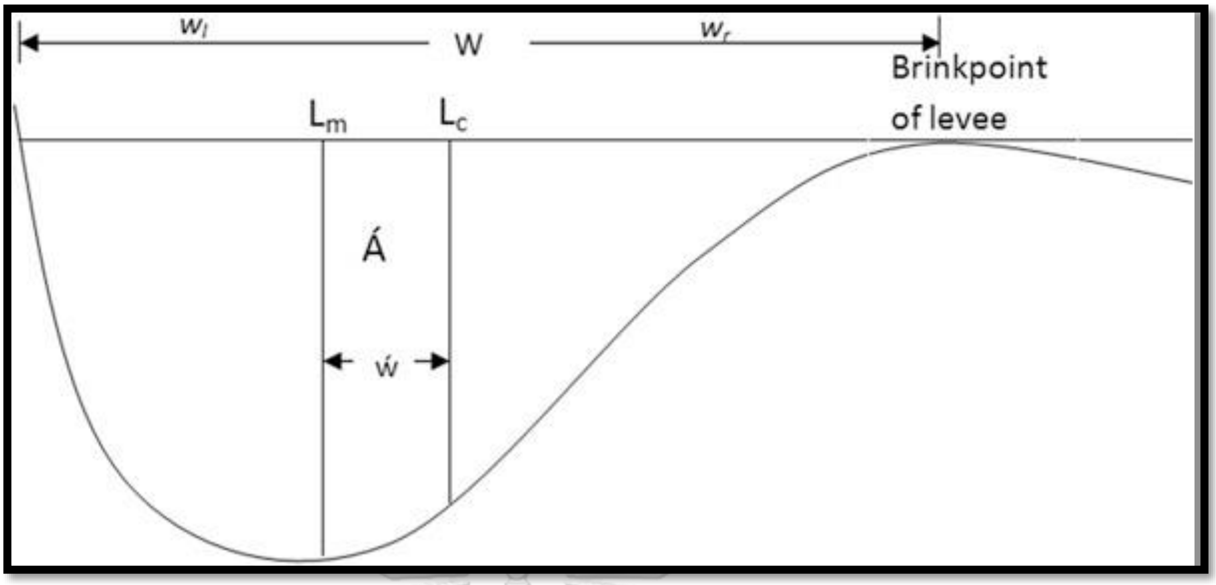

Figure 12 Definition of parameters of an asymmetrical channel (Das and Islam., 2018).

2.5 Geomorphological effect on downstream of dam

It has many purposes for construction dam such as irrigation, hydropower, flood mitigation (Richter & Thomas, 2007). Although construction dam has many advantages, it has many impacts on geomorphology in downstream area (Lai et al., 2017; D. Li, Lu, Chen, & Wasson, 2019; Makaske et al., 2012; Petts & Gurnell, 2005; Phillips, 2009; Williams & Wolman, 1984) . Brandt (2000) classified the geomorphological effect on downstream area of dam into 9 types: Water discharge, Sediment discharge, Bank erosion, Channel depth, channel planform, Bedform, cross-sectional area, migration rate.

2.5.1 Water Discharge

The effect on hydrological characterization in downstream area is one of primary effect from dam because dam controls all hydrological characterization in downstream area such as: peak flow, sediment carrying capacity, stream power, water quality (Brandt, 200). Li et al. (2017) found that the peak flows of downstream area of three gorges dam has reduced more than 40 % after the dam operated.

2.5.2 Sediment supply

The dam directly impacts on sediment transportation because almost of upstream sediments are trapped at the gate of dam. According to previous study (Dai & Liu, 2013; Lai et al., 2017; Lyu, Chai, Xu, Qin, & Cao, 2019), they found that downstream's sediment supply has dramatically decreased after the dam operated. Williams and Wolman (1984) found that the sediment trap efficiency of downstream area that is the ratio of amount of sediment deposition in upstream area and amount of sediment inflow directly varies with the size of dam. In some case, the sediment trap efficiency is higher than 90 %. The decreases of sediment supply led to many problems such as planform alteration, channel degradation, alteration in bed from.

2.5.3 Bank erosion

According to the reduction of down stream's sediment supply, it leads to the bank erosion in downstream area in case that most of downstream's sediments come from main channel. Thus, the channel width in downstream area will increased. Wang et al. (2018) found that Channel width Yichang-Chenglingji Reach, downstream area of three gorges dam in china reduced about 4.5 % after the dam has operated.

2.5.4 Channel Depth

According to the reduction of down stream's sediment supply, it can lead to channel degradation in case that river does not have erodible corridor. Many channel depth of downstream area has increased after the dam operated such as Aswan Dam in Egypt (Biswas, 2002) , Eildon Reservoir in Australia (Erskine, 1996) and Three gorges dam in China (Zhou, Xia, Lu, Deng, & Lin, 2017).

2.5.5 Cross-sectional area

According to the alteration in channel with and channel depth, the cross-sectional area will alter. Brandt (2000) concluded that the alteration in cross-sectional area influences to stream power and stability index.

2.5.6 Channel bed from

The dam always traps upstream sediment that influents to both of amount and size of downstream sediment (Brandt, 200). Schmidt and Wilcock (2008) found that the downstream channel bed has come to armoring status. The armoring means that the bed surface of gravel-bed rivers is coarsened relative to the sub-surface (Wilcock & DeTemple, 2005). The armoring condition influents to channel hydraulics, hydraulic roughness.

2.5.7 Slope alteration

Chien (1985) found that the slope of channel in downstream area has altered that is caused by the erosional process and alteration channel bed from. The slope alteration can impact on the transport capacity, shear stress and channel planform.

2.5.8 The Channel Planform

The channel planform depends on many factors: bed material, shear stress, slope, river energy. Brandt (2000) summarized that the alteration in channel width and channel depth causes the channel planform alteration. Sundborg (1956) found that the ratio of channel width and channel decreases. The channel will alter to meanders planform. For multiple channels, it found that many multiple channels in downstream area have altered to single channel such as Rio Grande in USA , Garone river in France (M. David, Labenne, Carozza, & Valette, 2016) and Tummel River in Scotland (Parsons & Gilvear, 2002). However, Słowik et al. (2018) found that downstream of Drava River in Hungary altered from sinuous (one channel) to anabranching pattern (multiple channels) after the dam had constructed.

2.5.9 Migration Channel

According to alteration in channel depth and channel width, migration rate of channel will be affected. Zhou et al. (2017) found that migration rate of downstream of Yangtze river has increased after the Three Gorges dam operated.

Chapter 3: Method

This thesis processing consists of 5 main steps: collecting data, creating a geomorphological map, delineation of reach, assessing the current river condition, and discussion & conclusion. Figure 13 shows the hierarchical framework of this thesis.

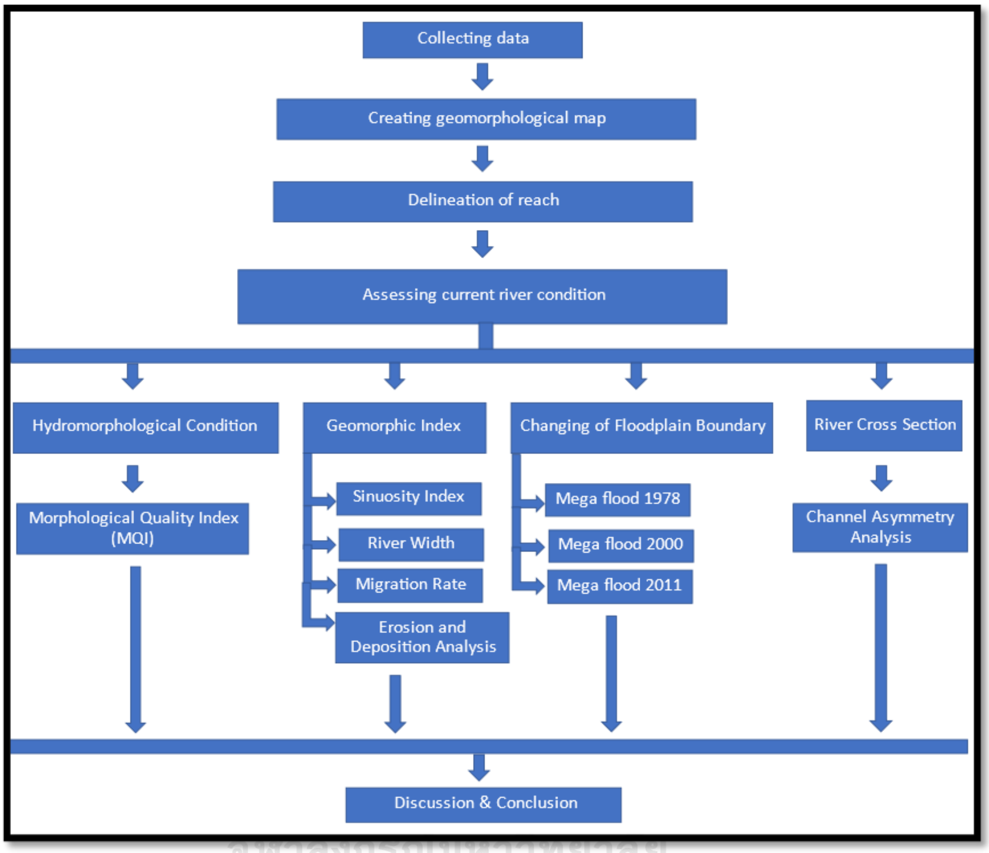

Figure 13 The hierarchical framework of this thesis.

3.1 Collecting data

The first Step is collecting data. The data that was used in the thesis is shown table 4. It consists of two main types: Remote Sensing data and Secondary data. First, Remote Sensing Data consists of Satellite image from Landsat 1-5 MSS in 1978, Landsat 4-5 TM in 1998, 2000, Google (Via Google Earth) in 2006 and 2020 and Aerial Photo taken by Royal Thai Survey in 1952 and 1992.The aerial photos in JPG version were rectified in ArcGIS 10.3 version. Each photos were rectified by using 12 ground control points from topographic map in UTM WGS 1984 zone 48N coordinated system. The ground control point means the points on the surface of the earth of known location such as the intersection of the road. The acquiring criteria for this study is the low value of Root Mean Square Error (RMSE). This thesis uses remote sensing data taken in both dry season and flood season. The remote sensing data taken in the dry season was used for defining river boundary and calculating geomorphic index because the sky doesn't have more clouds, and water remains in the river (Gurnell, Downward, & Jones, 1994). The dry season remote sensing consists of five periods: 1952, 1988, 1992, 2006, and 2020. The remote sensing data taken in flood season was used to define the boundary of mega-flood. It consists of two periods: 1978 and 2000. Second, Secondary data consists of shapefile, geological map, topographic map, cross-sectional data, and run-off data. The shapefile is the boundary of mega-flood in 2011 that GISTDA created. The geological map was created on a scale of 1: 50,0000 by the Department of Mineral Resource (Thailand) in 2008, consisting of two sheets: 5541 I and 5641 IV. Next, the topographic map was produced on a scale of 1: 50,000 by the Royal Thai Survey that consists of two sheets: 5541 I and 5641 IV. Next, runoff data was collected data by Royal irrigations at Ban Kuichaug bridge in January 2020. Finally, run off data has been collected data by Royal irrigations at Ban Kuichaug bridge since 2006.

Remote Sensing Data			
Type	Taken by	Date taken	Resolution of image
Aerial Photo	Royal Thai Survey	1952	0.6 meter
		1992	0.6 meter
Satellite Image	Landsat 1-5 MSS	10/30/1978	30 meters
	Landsat 4-5 TM	20/02/1988	30 meters
		10/10/2000	30 meters
	Google (Via Google Earth)	2006	1 meter
		2020	1 meter
Secondary Data			
Type	Created by	Sheet	Application Data
Shape File	GISTDA	Thailand	Defining flood event 2011 boundary
Geological Map (1:50,000)	DMR (Thailand)	5541 I	Defining geological unit
		5641 IV	Defining geological unit
Topographic Map (1:50,000)	Royal Thai Survey	5541 I	Using in field survey
		5641 IV	Using in field survey
River Cross section (Jan 2020)	Royal Irrigation Department	Station E9.1	Comparing with river cross section (October 2020)
Run off Data			Comparing run off in each month

Table 4 Detail of data used in this thesis.

3.2 Creating geomorphological map

This thesis created a geomorphological map in two periods: 1952 and 2020 because remote sensing taken in 1952 and 2020 has an appropriate resolution for crating detail maps. In each period map was produced in two spatial scales: Board level and Basic level. First, the board level shows the boundary of five macro units following GUS Method (Barbara Belletti et al., 2017): baseflow, Emergent sediment, Floodplain aquatic Zone, Riparian Zone, and Channel vegetation. Second, the basic level has more detail than the board level. It shows the boundary of the unit. The boundary of the Floodplain in the geomorphological map was based on the boundary of mega-flood in the study area that was cited from three mega-flood events: 1978, 2000, and 2011.

It has four steps for creating the geomorphological map. The first step is rectifying aerial photos and satellite images. The second step is mosaicing the image. The third step is defining the boundary of 5 macro units. Finally, it is determining the unit in each macro unit. The geomorphological map in 1952 used floodplain boundary from the boundary of 1978 mega-flood, while the geomorphological map in 2020 used floodplain boundary from the boundary of 2011 mega-flood. Every step is doing in ArcGIS program version 10.3. The third step is leading to Board level geomorphological map, and the result of the fourth step is leading to a basic geomorphic level.

For application, the geomorphological map will describe confinement conditions and geomorphological alteration of the Chi River in Muang Khon Kaen district and adjacent areas.

3.3 Delineation of reach

Delineation of reach is dividing the study area to reach scale. The reach scale means the small area that has a similar morphological channel. The delineation of reach delineates from Chi river in 2020 because this condition is the most current condition. These steps use many delineating criteria that consist of confinement condition, channel planform, geological condition, river's orientation, floodplain feature, and artificial element that affects the river and riparian zone such as bank protection.

3.4 Assessing current river condition

Assessment current river condition consists of four parts: hydromorphological condition, geomorphic index value, Changing of floodplain boundary, and degree of asymmetry.

The first part, changing flood boundary, compared the alteration of mega flood's boundary in three periods: 1978, 2000, and 2011.

The second part analyzes the geomorphic index that concludes: Sinuosity index, Channel width, Widening rate and Migration rate. The migration rate was calculated from mid channel's migration rate. These indices were calculated from aerial photos and satellite images that were taken in the dry season. The study area has significant construction that as the irrigation dam that was constructed in 1988 and was operated in1992. According to a previous study (e.g., Williams and Wolman 1984, Petts and Gurnell 2005), the dam construction affects the downstream channel geometry. Thus, the geomorphic index was measured in 1988 and 1992 for detecting geomorphic alteration during the construction of the Irrigation dam. The channel width and The Sinuosity index were measured in 5 periods: 1952, 1988, 1992, 2006, and 2020, while widening rate and migration rate were measured in 4 periods: 1952-1988, 1988-1992, 1992-2006, and 2006-2020. The channel width, the widening rate, and the migration rate was measured for every river length 100 meters. Thus, it has 670 stations that is shown in Figure 14.

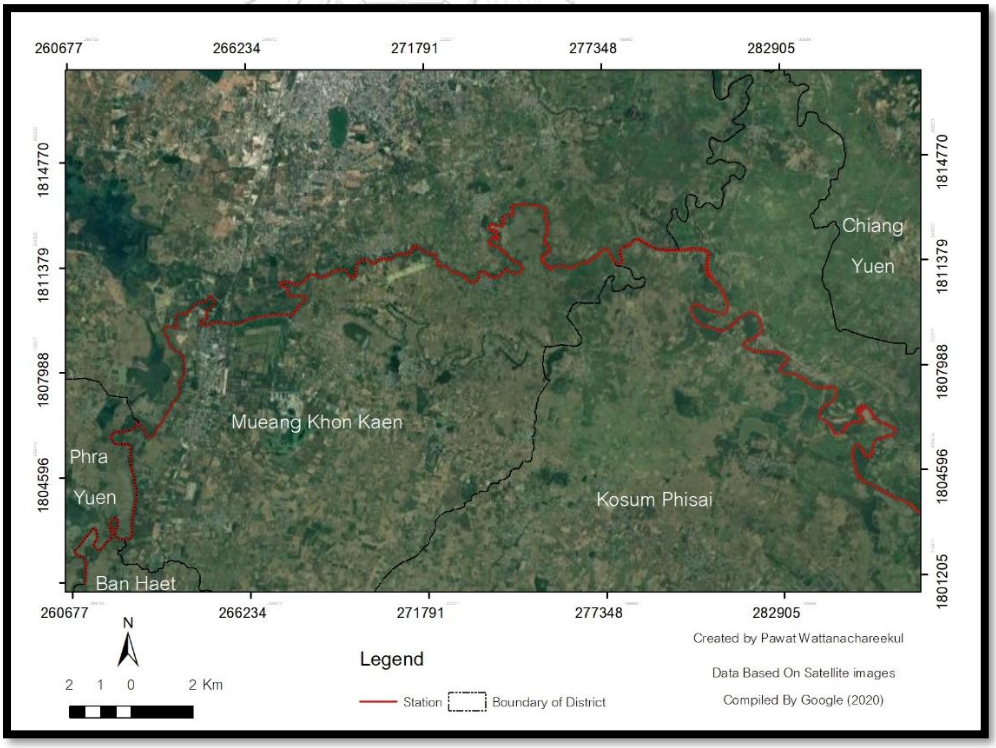

Figure 14 The location of 670 stations that were measured geomorphic index.

The third part, hydromorphological condition, was evaluated by the Morphological Quality Index (MQI) that described the degree of alteration and distribution of reach scale in terms of related score. The MQI consisted of 28 indicators that are shown in table 3 in chapter 2. These indicators can be classified into three elements: artificiality, channel adjustment, and geomorphic functionality. In each element can be calculated the percentage. If the percentage is high, it means the level of alteration in this topic is high. First, artificiality evaluates the number of artificial elements and intervention processes. The percentage of artificiality can be calculated the percentage that as follows equation 3.1. Next, the geomorphological functionality evaluates whether or not an artificial element and channel adjustment alter the river process and morphological conditions. The percentage of geomorphic functionality can be calculated the percentage that as follows equation 3.2. Finally, channel adjustment evaluates the degree of alteration of the channel river. The percentage of channel adjustment can be calculated the percentage that as follows equation 3.2. Finally, geomorphological functionality evaluates whether or not an artificial element and channel adjustment alter the river process and morphological conditions. The percentage of geomorphic functionality can be calculated the percentage that as follows equation 3.3. After calculation in each component, the MQI score can be calculated as follows equation 3.4. The detail of score in each indicator is shown in Appendix A.

$$\% \text{ artificiality} = \frac{\text{Sum score of A1 to A12}}{\text{Sum of Maximum score of A1 to A12}} \qquad \text{(Equation 3.1)}$$

$$\% \text{ Geomorphological Functionality} = \frac{\text{Sum score of F1 to F13}}{\text{Sum of Maximum score of F1 to F13}} \qquad \text{(Equation 3.2)}$$

$$\% \text{ Channel adjustment} = \frac{\text{Sum score of CA1 to CA3}}{\text{Sum of Maximum score of CA1 to CA3}} \qquad \text{(Equation 3.3)}$$

$$\text{MQI score} = 1 - \frac{\text{Sum score of all indicators}}{\text{Sum of Maximum score of all indicators}} \qquad \text{(Equation 3.4)}$$

The fourth part is calculating the degree of asymmetry channel from cross-sectional shape that was collected from 5 bridges in Chi River that is shown in Figure 15. The cross-sectional shape was collected by dropping the rope with weighting every 10 meters in the horizontal distance.

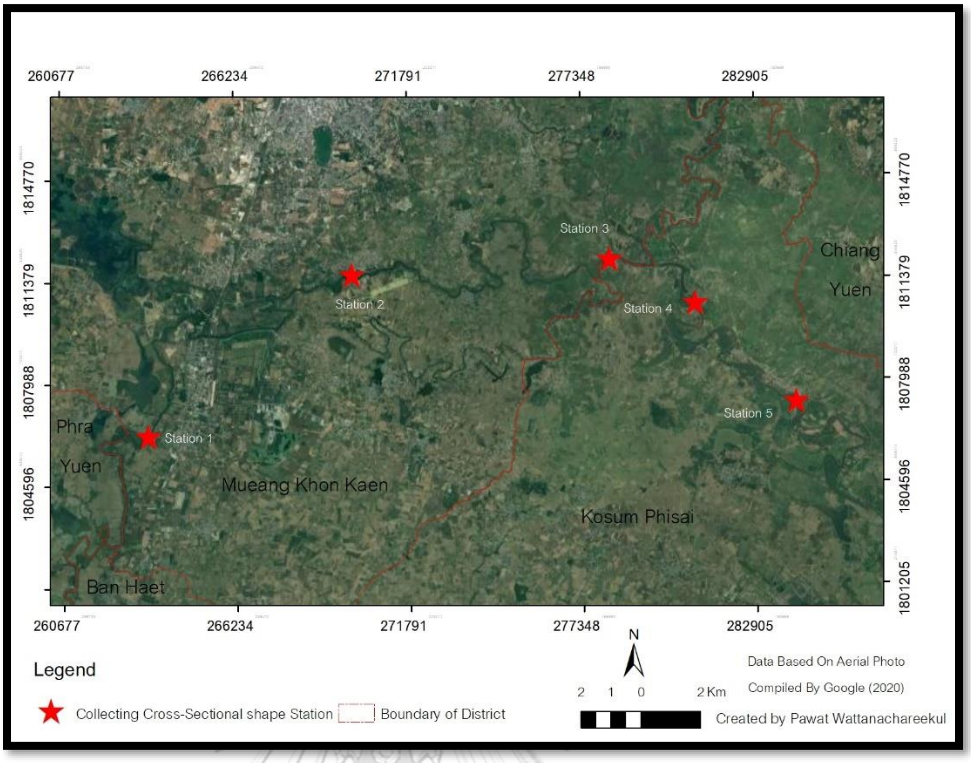

Figure 15 The location of 5 stations that were collected cross-sectional data.

The degree of asymmetry was calculated by six indices: A*, A1, and A2 from Knighton (1981) and Aa, Aw, and Awa from Das and Islam (2018). The A* calculates the degree of spatial asymmetry of channel that can be calculated as follows equation 2.2 in chapter 2. The A1 calculates the degree of horizontal asymmetry of channel that can be calculated as follows equation 2.3 in chapter 2. The A2 calculates the degree of vertical asymmetry of channel that can be calculated as follows equation 2.4 in chapter 2. Aa calculates the degree of spatial asymmetry that can be calculated as follows equation 2.5 in chapter 2. Aw calculates the degree of horizontal asymmetry that can be calculated as follows equation 2.6 in chapter 2. Finally, Awa is the product of Aw and Aa that can be calculated as follows equation 2.7 in chapter 2.

For the area of cross-sectional shape, it can be calculated by the area between two curves (x_y_curve1 is cross-sectional shape and x_y_curve2 is water level) in google colab. The code that was used for calculating the area of cross-sectional in google colab is following that

```
from shapely. Geometry import Polygon

x_y_curve1 = [(X1,Y1), (X2,Y2)]

x_y_curve2 = [(Xa, Ya), (Xb, Yb)]
```

```
polygon_points = [] #creates a empty list where we will append the points to create the polygon
for xyvalue in x_y_curve1:
    polygon_points.append([xyvalue[0],xyvalue[1]])
for xyvalue in x_y_curve2[::-1]:
    polygon_points.append([xyvalue[0],xyvalue[1]])
for xyvalue in x_y_curve1[0:1]:
    polygon_points.append([xyvalue[0],xyvalue[1]])
polygon = Polygon(polygon_points)
area = polygon.area
print(area)
```

3.5 Discussion and Conclusion

The discussion part discusses all results from remote sensing analyses and field surveys leading to assessing the Chi river's hydromorphological changes in Khon Kaen. It consists of four parts. The first part, changing of flood boundary, discusses the changing of mega-flood in thre0e periods: 1978, 200, and 2011. The second part, asymmetry of the channel, discusses the degree of asymmetry channel that was calculated from 6 indices: A*, A1, and A2 from (Knighton, 1981) and Aa, Aw, and Awa (Das and Islam, 2018). In addition, this part compares the cross-sectional data that was collected at Ban Kuichaug bridge between January 2020 and October 2020. The third part, the geomorphic index alteration, discusses the alteration of geomorphic index value in each period. In addition, this part compared the alteration of the geomorphic index in between downstream and upstream of an irrigation dam. The fourth part is the relationship between geomorphic index changes and MQI Score. This part compares geomorphic index alteration in the High MQI score area and Low MQI Score area.

The conclusion part is concluding interesting data from the thesis and giving some suggestions for future study and benefits from this study.

Chapter4: Results

This chapter provides the study results, including a geomorphological map, changing of mega floodplain boundary, hydromorphological condition, geomorphic index, and channel asymmetry. Results were divided into 6 parts, starting with the geomorphological map. As mentioned in the previous chapter, the geomorphological map was used to delineate the study area to reach scale. The geomorphological map was produced from aerial photos taken in 1952 and satellite images taken in 2020 because these data sets have appropriate resolutions for creating a geomorphological map. In this chapter, the changing of flood boundary was produced from mega-flood boundary in a study area in different three periods: 1978, 2000, and 2011. The third part of this chapter, Delineation of reach divided all study areas into 25 reach scales based on the river's orientation, the planform of the river, and artificial elements in this area. The fourth part of this chapter, Geomorphic Index, consisted of Sinuosity Index, channel width, Migration Rate was measured in the dry season in five different periods: 1952, 1988, 1992, 2006, and 2020. Also, this part compared erosion areas and deposition areas of the Chi River in the study area between 2006 and 2020 that were collected data in the dry season. The fifth part of this chapter, Hydromorphological condition in 2020 was assessed by the Morphological Quality Index (MQI) (Rinaldi et al., 2013). MQI revealed the term of hydromorphological alteration in terms of relative scores. Last part of this chapter, Channel asymmetry was analyzed by two sets of asymmetry indices: A*, A1, and A2 from Knighton (1981) and Aa, Aw, and Awa from B. C. Das and Islam (2016) from a cross-sectional shape that was collected data from 5 locations in October 2020. All results will give essential information on hydrology coupled with geomorphology for river management in the study area.

4.1 Geomorphological map

This thesis has two spatial scales: board level and basic Level. The board level shows the boundary of Macro Unit in study area.

4.1.1 Geomorphological board level

4.1.1.1 Geomorphological Map board level in 1952

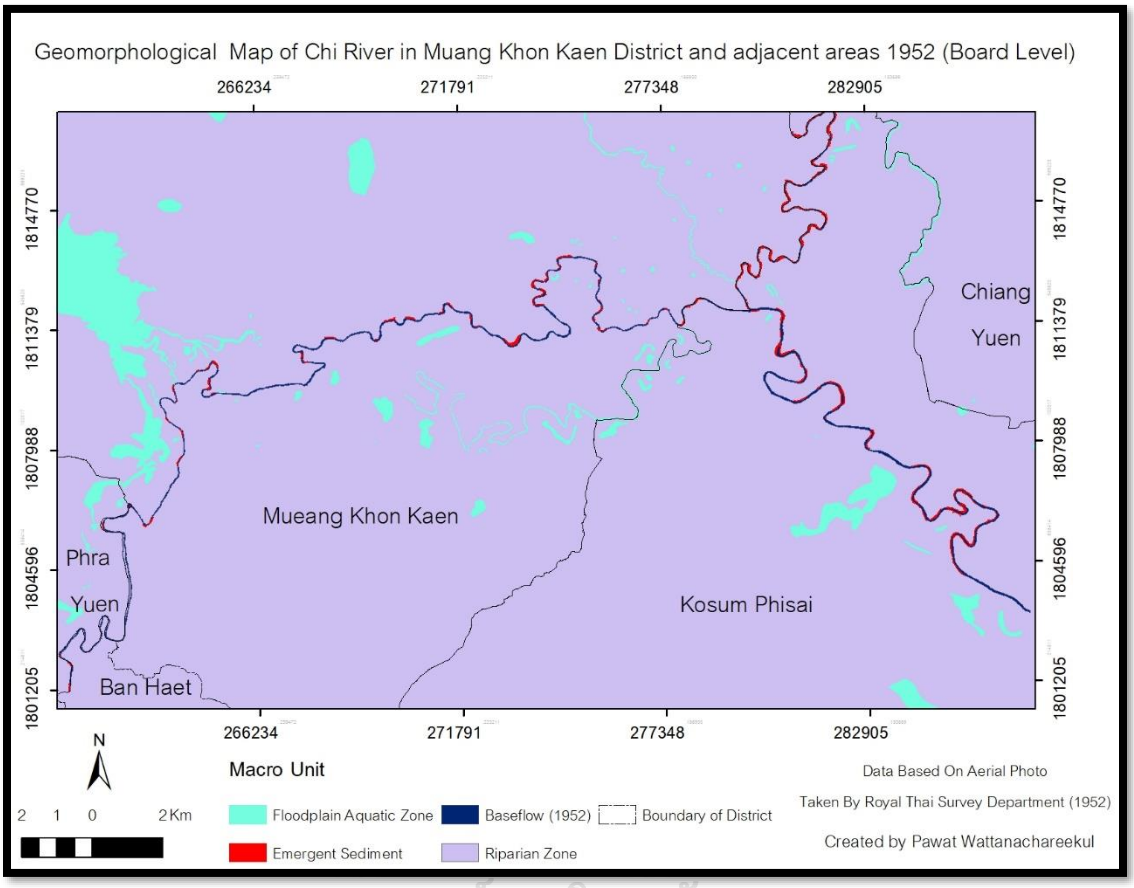

Figure 16 The Chi river's geomorphological board level map in Muang Khon Kaen district and adjacent areas in 1952.

Figure 16 shows the Chi river's geomorphological board level map in Muang Khon Kaen district and adjacent areas in 1952. This map is produced from aerial photos that were taken in 1952. According to the figure, it can be seen that this geomorphic consists of 4 Macro Unit: Base Flow unit that displays as dark blue color, Emergent sediment that displays as red color in the map, Floodplain Aquatic Zone that displays as light blue color in the map and Riparian Zone that displays as purple color in the map.

4.1.1.2 Geomorphological map Board level in 2020

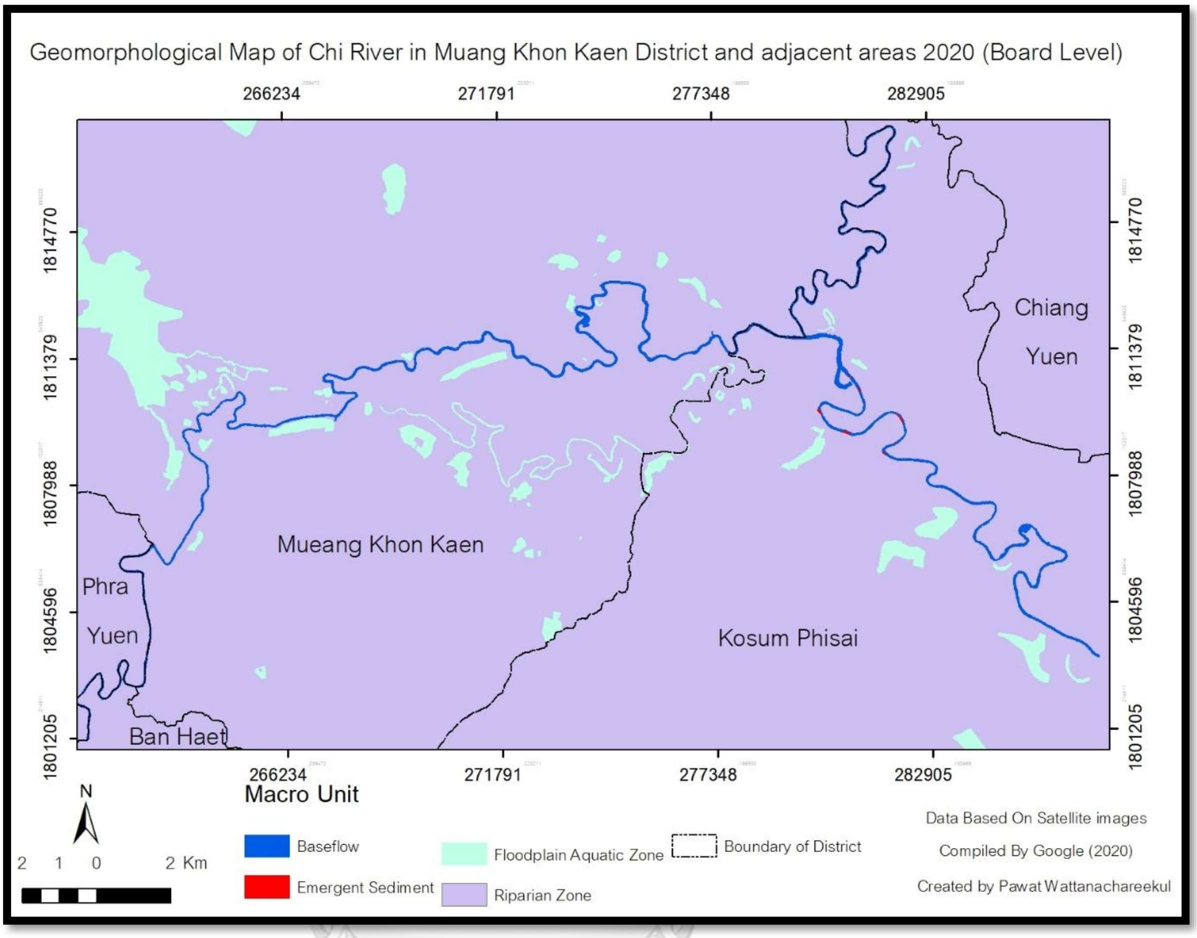

Figure 17 The Chi river's geomorphological board level map in Muang Khon Kaen district and adjacent areas in 2020.

Figure 17 shows the geomorphological board level map of the Chi River in Muang Khon Kaen district and adjacent areas in 2020. This map is produced from satellite images that were taken in 2020. According to the figure, it can be seen that this geomorphic consists of 4 Macro Unit: Base Flow unit that displays as dark blue color, Emergent sediment that displays as red color in the map, Floodplain Aquatic Zone that displays as light blue color in the map and Riparian Zone that displays as purple color in the map.

4.1.2 Geomorphic basic level

4.1.2.1 Geomorphic basic level in 1952

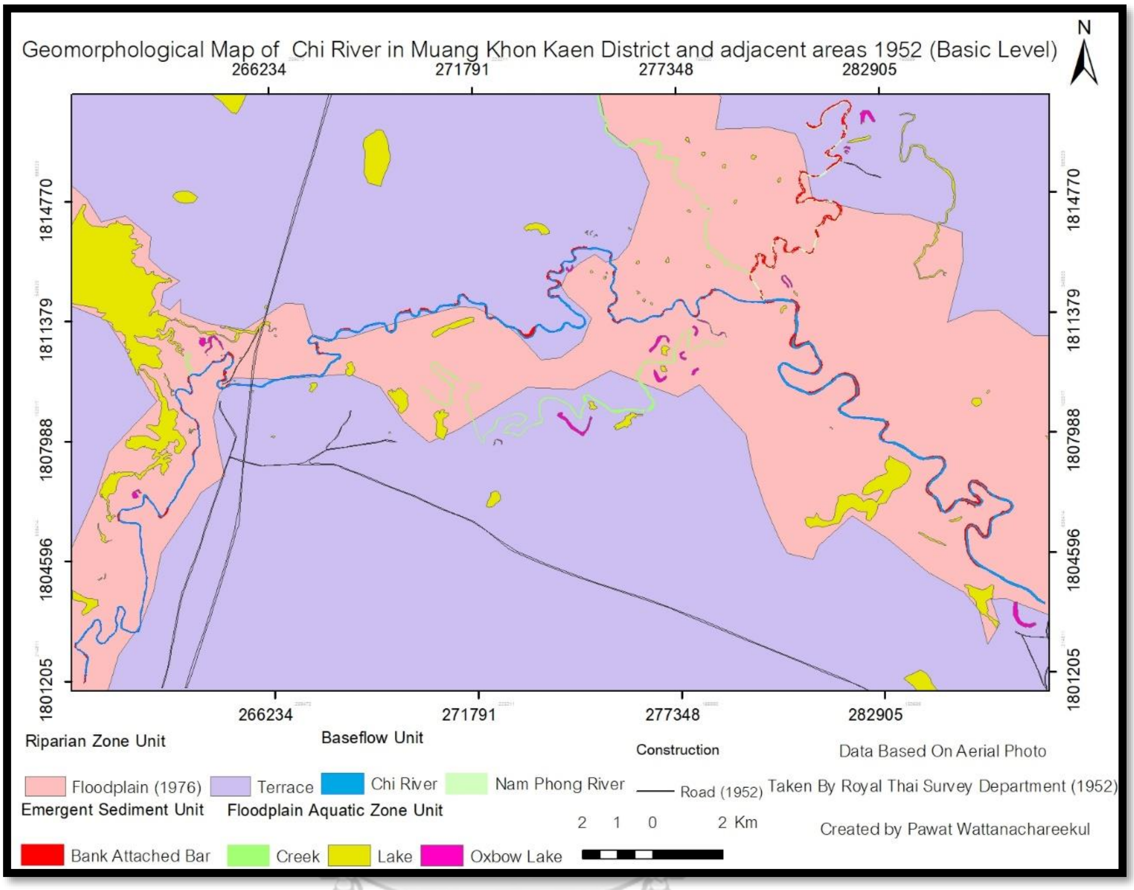

Figure 18 The Chi river's geomorphological basic level map in Muang Khon Kaen district and adjacent areas in 1952.

Figure 18 shows the geomorphological board-level map of the Chi River in Muang Khon Kaen district and adjacent areas. This map is produced from aerial photos that were taken in 1952. According to the map, the baseflow unit consists of 2 units: Chi river and Nam Phong river. The emergent sediment unit has only a bank attached bar. Next, Flood plain aquatic unit consists of three units: Creek, lake, and Oxbow lake. Finally, the Riparian unit consists of 2 units: terrace, and floodplain. The floodplain is cited from1978 mega-flood boundary.

4.1.2.1 Geomorphic basic level in 2020

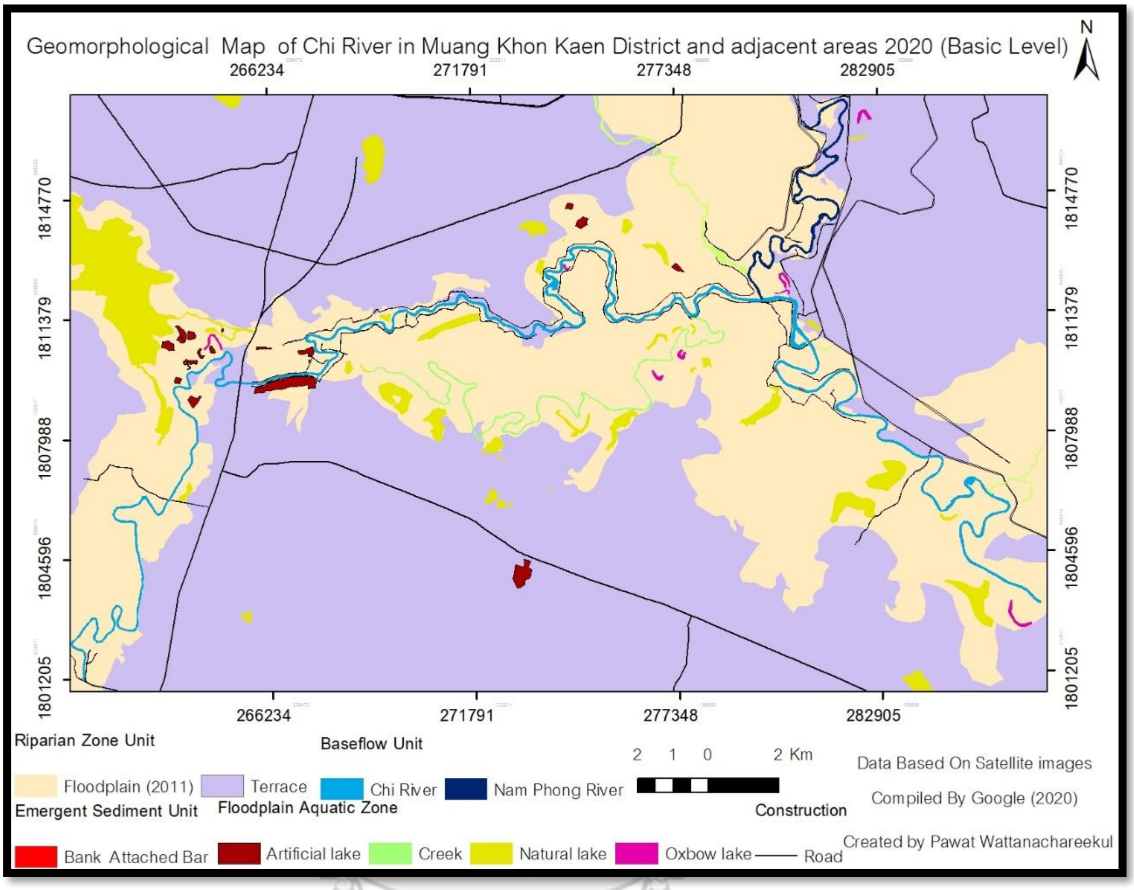

Figure 19 The Chi river's geomorphological basic level map in Muang Khon Kaen district and adjacent areas in 2020.

Figure 19 shows the geomorphological basic level map of the Chi River in Muang Khon Kaen district and adjacent areas. This map is produced from satellite photos that were taken in 2020. According to the map, the Baseflow unit consists of 2 units: Chi river and Nam Phong river. For Emergent sediment unit, it consists of one unit: bank attached bar. Next, Flood plain aquatic unit consists of three units: Creek, lake, and Oxbow lake. Finally, Riparian unit consists of 3 units: Abandoned paleochannel, terrace, and floodplain. The floodplain was cited from the mega-flood boundary in 2011. For construction, this study area consists of Bank protection, Road, and Dam. Nowadays, the number of roads is more than in 1952.

4.1.3 Confinement index

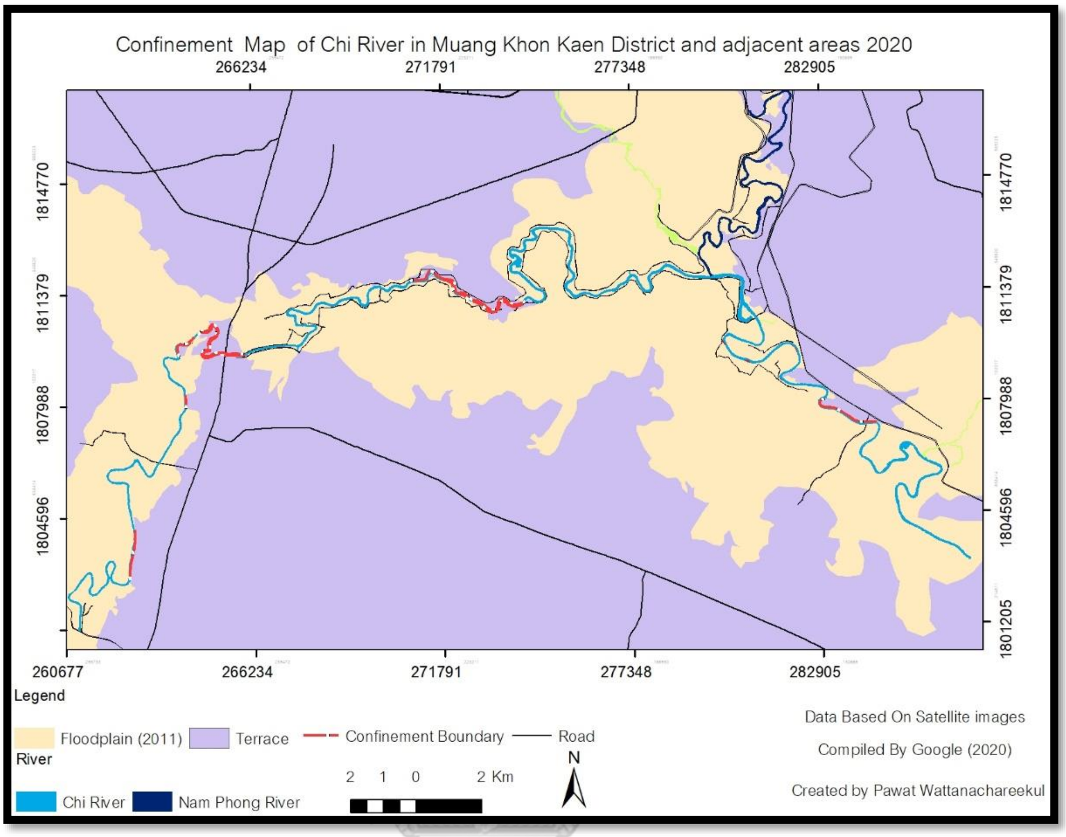

Figure 20 Confinement map of Chi rivermap in Muang Khon Kaen district and adjacent areas.

Figure 20 shows the boundary of confinement (the area is abutted by inactive floodplain area) in Chi River in Muang Khon Kaen district and adjacent areas. It can be calculated that the length of the Chi river in 2020 is 67,293.1 meters and the length of river that is abutted by inactive floodplain area is 11431.44 meters. Thus, the confinement index is 16.98 %. This study area is classified as the partly confined condition.

4.2 Changing of flood boundary

According to geomorphological maps, it can be seen that land uses and land cover in the study area have many alterations. Shrestha, Ye, and Khadka (2019) found that land use and land cover changes have impacts on flood hazards. Thus, this is a reason to produce the map of changing flood boundaries. This process is obtained data from the boundary of mega flooded in the study area in three different periods: 1978, 2000, 2011 that have many alterations. Figure X Shows the changing of flood boundary that can divide the changing boundary into 6 areas. The first area is grey color on the map that means this area was suffered from the flood in 1978. The second area is orange color on the map that means this area was suffered from the flood in 1978 and 2000.

The third area is green color on the map that means this area was suffered from the flood in 2000 and 2011. The fourth area is yellow color on the map that means this area was suffered from the flood in 2011. The fifth area is yellow color on the map that means this area was suffered from the flood in 1978, 2000 and 2011. The sixth area is red color on the map that means this area does not have suffered from the flood.

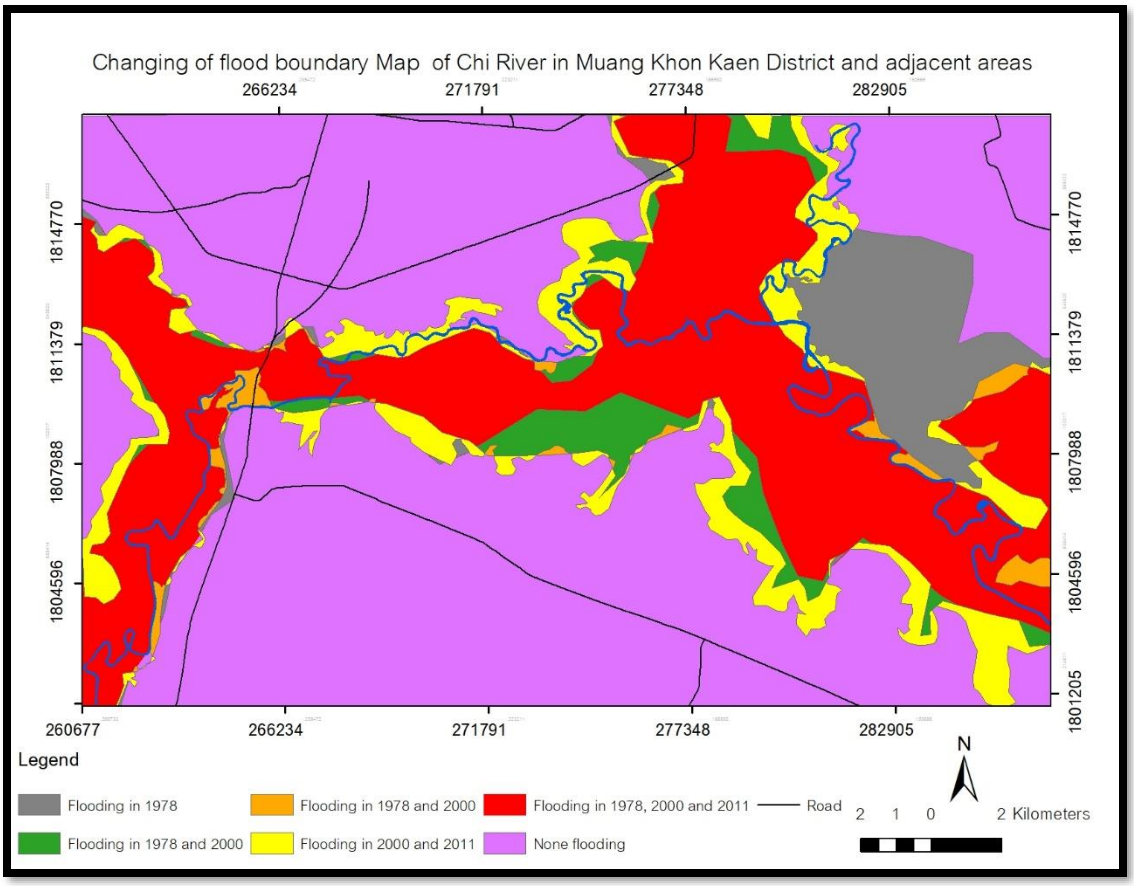

Figure 21 The changing of flood boundary map of Muang Khon Kaen district and adjacent areas.

4.3 Reach delineation

Reach delineation was divided by confinement condition, the orientation of river, channel planform, artificial elements. The first step is dividing the study area into segment scale. Segment scale is portions of landscape with similar confinement conditions that can be defined boundary by confinement degree and confinement index. However, the Geomorphological map of this thesis reveals that the study area has confinement conditions as unconfined. Thus, this step uses the orientation of the river to divide the study area into segment scale. It can divide into 3 segments

(Figure 22). The first segment is the Chi river that orientates in the Northeast – Southwest direction. The second segment is the Chi river that orientates in the East-West direction. This segment is yet to meet Nam Pong River, branch river of Chi river. The last segment is the Chi river that orientates in North West- South East direction and meets the Nam Phong river.

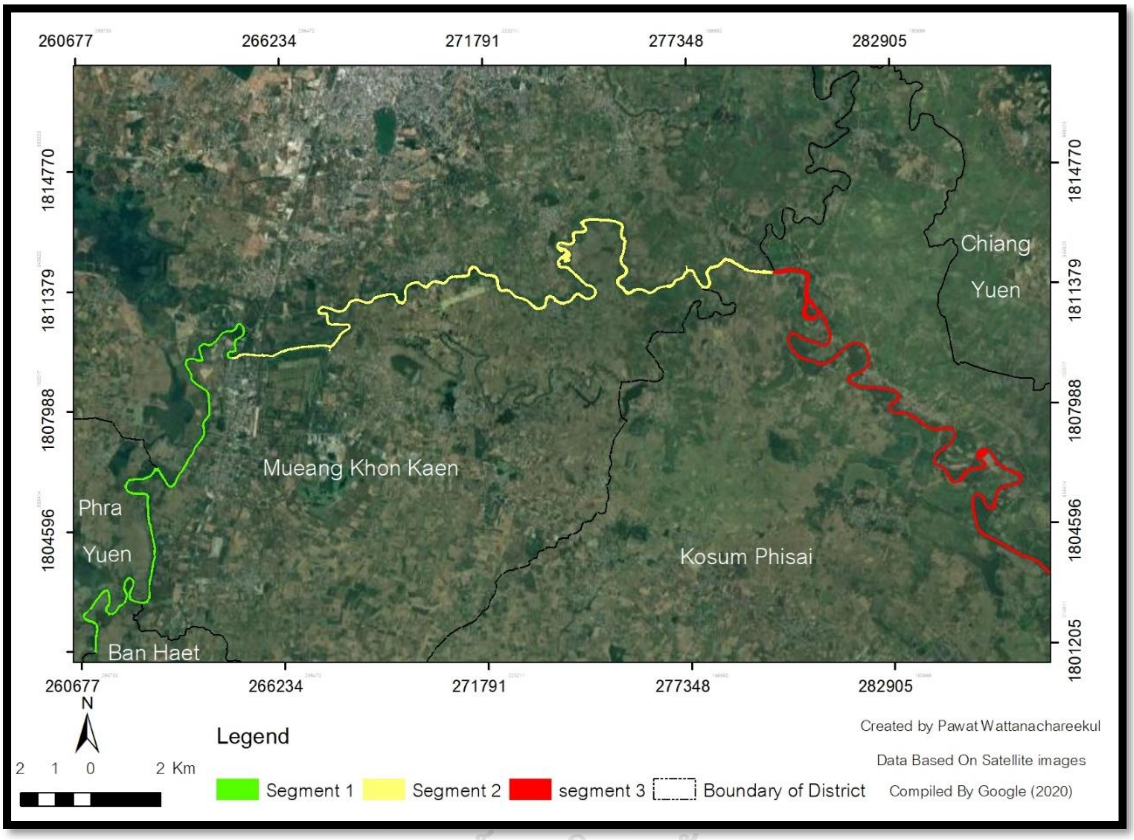

Figure 22 Segment scale of Chi river in Muang Khon Kaen district and adjacent areas.

After dividing river to segment scale, the next step is dividing each segment scale to reach scale. Reach scale means a small area that has a similar degree of artificial elements and morphology of river. The length of reach scale is from 100 meters to 10 kilometers. Segment 1 can divide into 10 reaches (Reach 1 -10), while segment 2 can be divided into 9 reaches (Reach 11-19), and Segment 3 can be divided into 6 reaches (Reach 20-25). Thus, it has 25 reaches. The Figure 23 shows boundary of each reach scale.

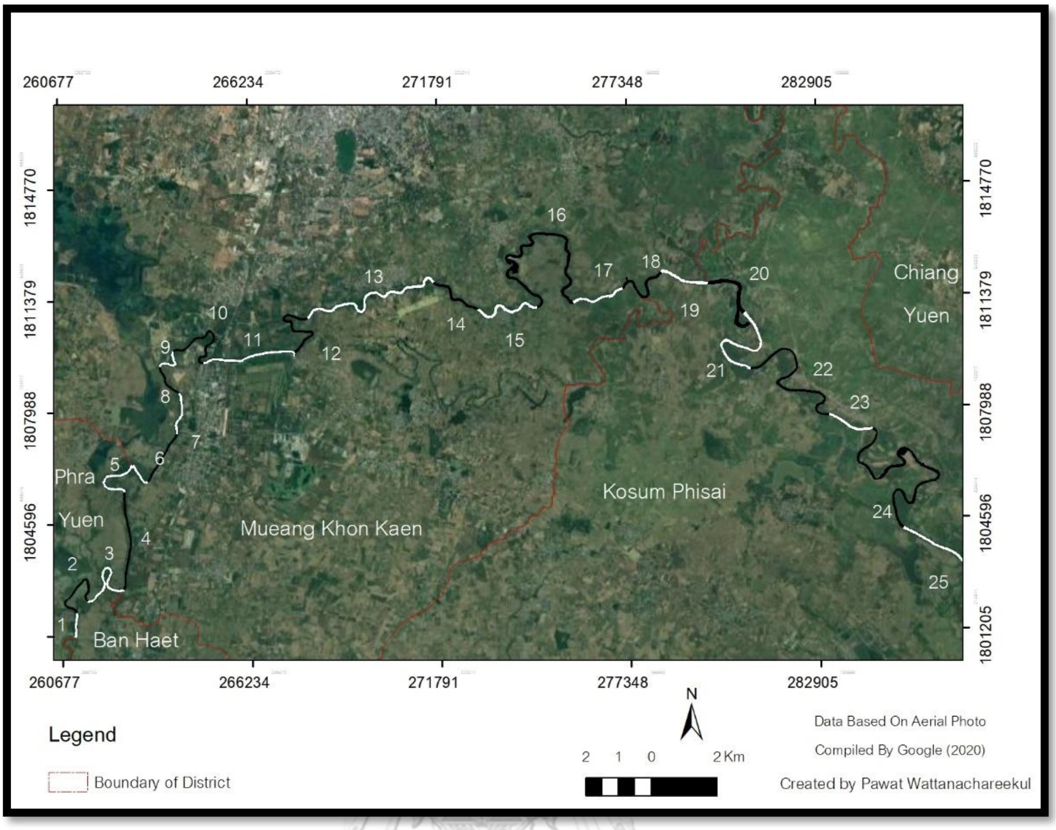

Figure 23 Reach scale of Chi river in Muang Khon Kaen district and adjacent areas.

4.3.1 Detail of each reach.

4.3.1.1 Detail of Reach 1

Figure 24 shows the condition of reach 1 in 1952 and 2020. Reach 1 is the straight river that orientates in the Northeast-Southwest direction. This reach is 747.54 meters long. For artificial elements, this reach has one bridge that crosses over the river.

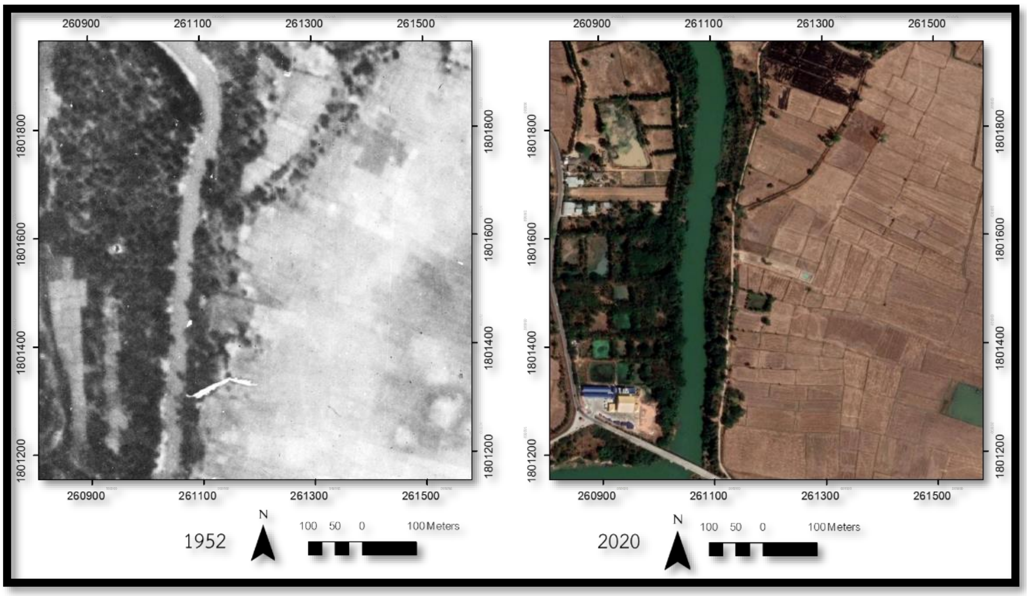

Figure 24 Close up air-photo and satellite image of Reach 1.

4.3.1.2 Detail of Reach 2

Figure 25 shows the condition of reach 2 in 1952 and 2020. Reach 2 is a meandering river that orientates in the Northeast-Southwest direction. This reach is 2190.79 meters long. This reach doesn’t find any artificial element, but the riparian zone has changed from an abandoned channel to a lake.

Figure 25 Close up air-photo and satellite image of Reach 2.

4.3.1.3 Detail of Reach 3

Figure 26 shows the condition of reach 3 in 1952 and 2020. Reach 3 is a meandering river that orientates in the East-West direction. This reach is 2494.64 meters long. This reach has a high probability of cutting off in the future.

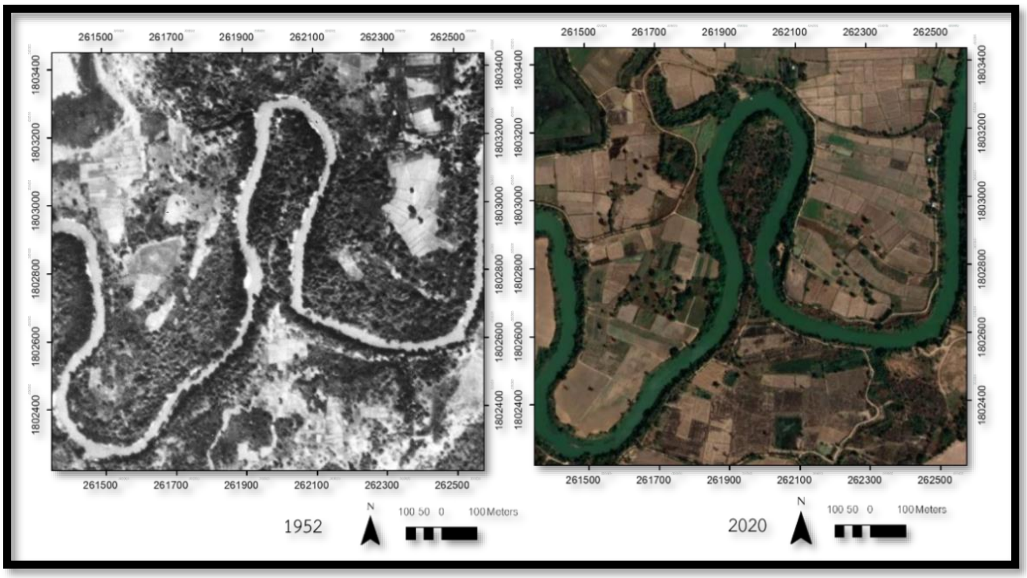

Figure 26 Close up air-photo and satellite image of Reach 3.

4.3.1.4 Detail of Reach 4

Figure 27 shows condition of reach 4 in 1952 and 2020. This reach is straight river that orientates in North-South direction. This reach is 3003.5 meters long. This reach has no any artificial element.

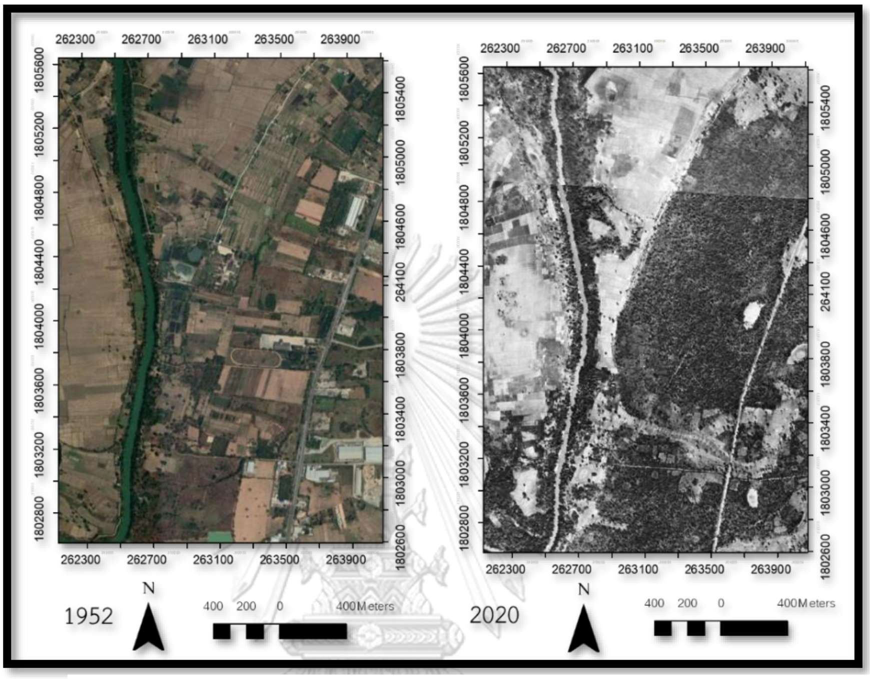

Figure 27 Close up air-photo and satellite image of Reach 4.

4.3.1.5 Detail of Reach 5

Figure 28 shows condition of reach 5 in 1952 and 2020. This reach is meandering river that orientates in East-West direction. This reach is 2509.16 meters long. This reach has no any artificial element but many vegetation areas have been removed.

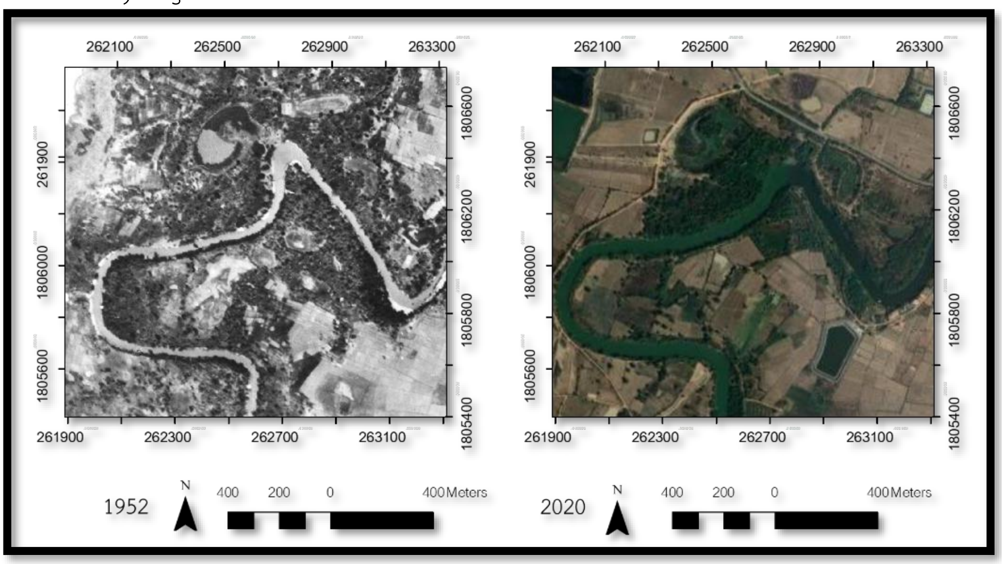

Figure 28 Close up air-photo and satellite image of Reach 5.

4.3.1.6 Detail of Reach 6

Figure 29 shows condition of reach 6 in 1952 and 2020. Reach 6 is straight river that orientates in Northeast-Southwest direction. This reach is 1685.72 meters long. This reach has one bridge and water supply powerplant.

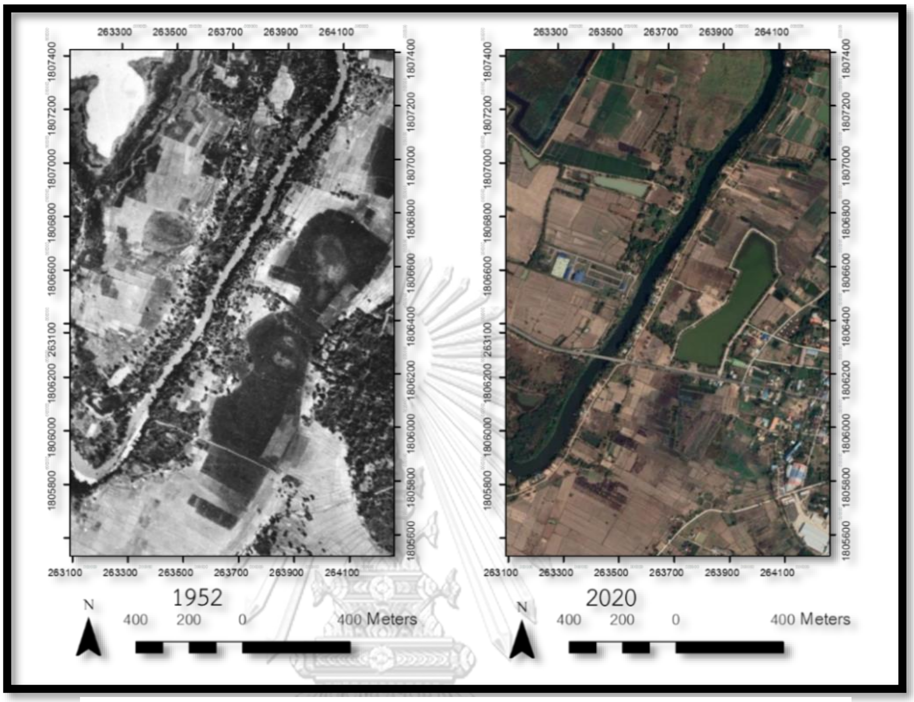

Figure 29 Close up air-photo and satellite image of Reach 6.

4.3.1.7 Detail of Reach 7

Figure 30 shows condition of reach 7 in 1952 and 2020. Reach 7 is sinuous river is sinuous river that orientates in North-South direction. This reach is 1329.84 meters long. The paleochannel of this reach has been changed to lake.

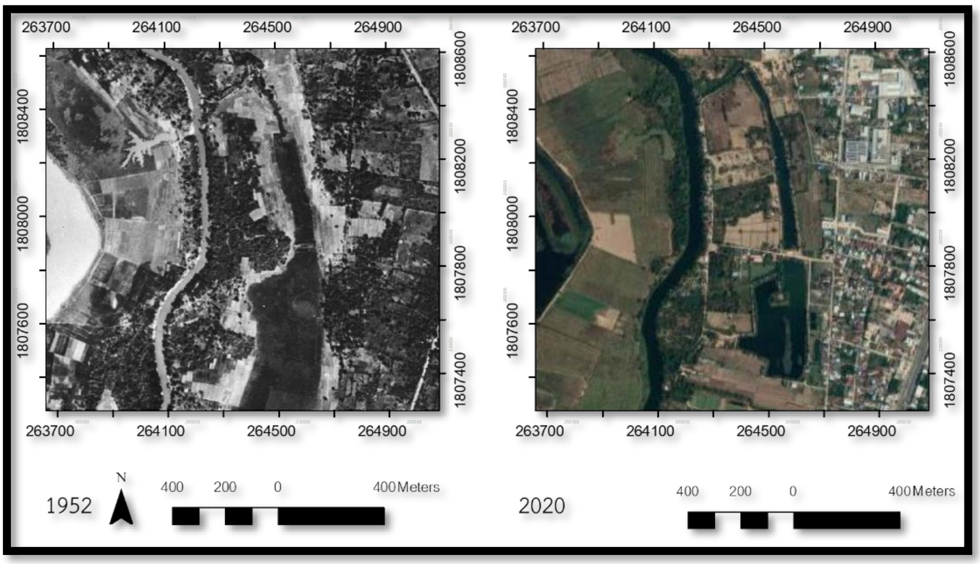

Figure 30 Close up air-photo and satellite image of Reach 7.

4.3.1.8 Detail of Reach 8

Figure 31 shows condition of reach 8 in 1952 and 2020. Reach 8 is straight river that orientates in Northeast-Southwest direction. This reach is 1003.59 meters long. Many vegetation areas of this reach have been removed. Moreover, the paleochannel has been changed to lake.

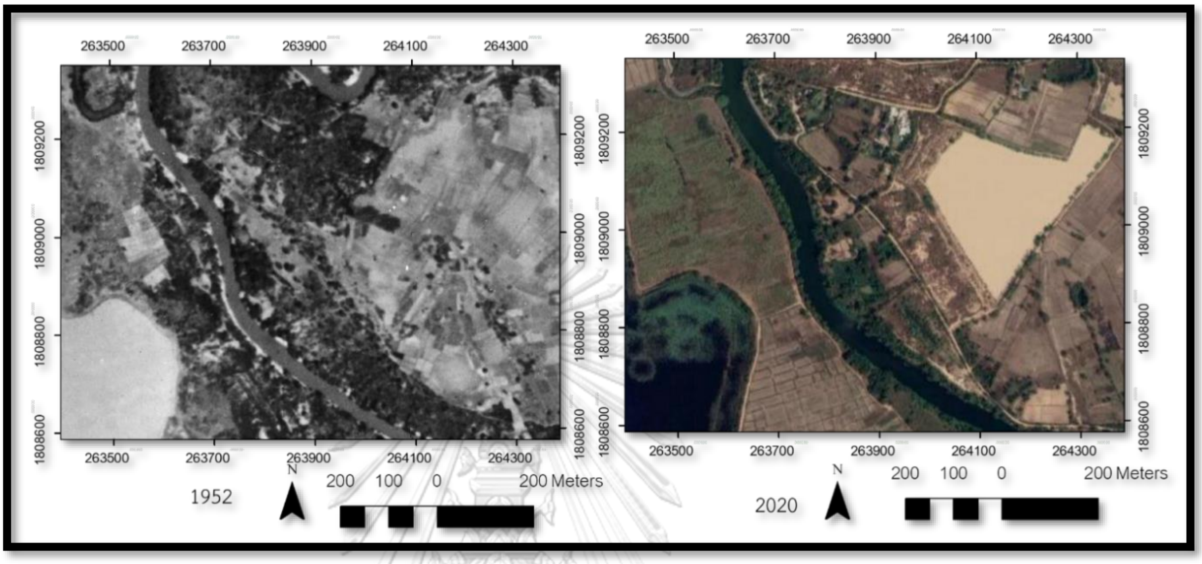

Figure 31 Close up air-photo and satellite image of Reach 8.

4.3.1.9 Detail of Reach 9

Figure 32 shows condition of reach 9 in 1952 and 2020. Reach 9 is meandering river that orientates in Northeast-Southwest direction. This reach is 914.35 meters long. Many vegetation areas of this reach have been removed.

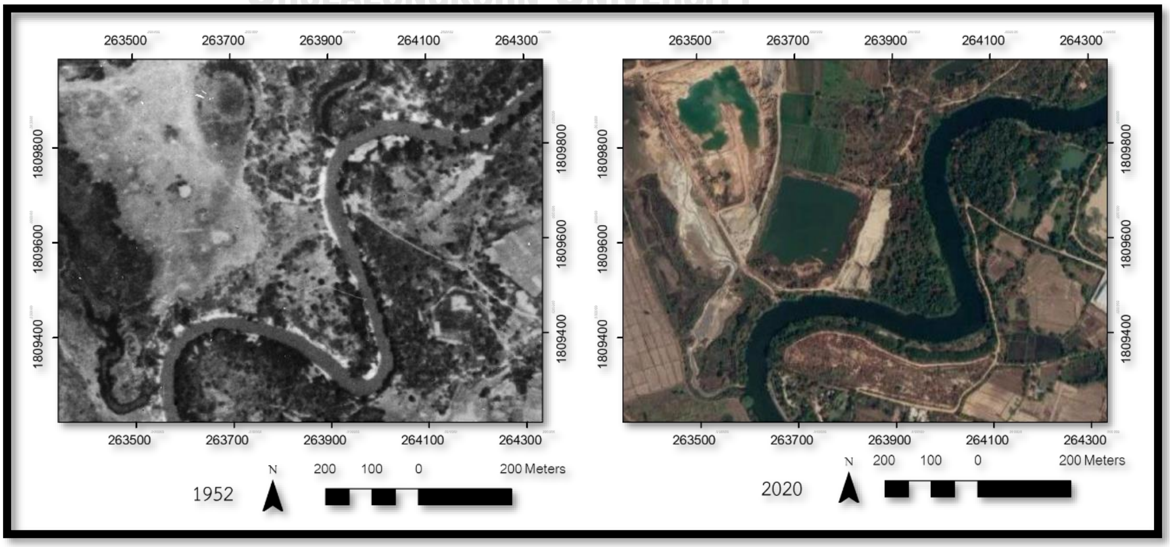

Figure 32 Close up air-photo and satellite image of Reach 9.

4.3.1.10 Detail of Reach 10

Figure 33 shows condition of reach 10 in 1952 and 2020. Reach 10 is meandering river that orientates in East-West direction. This reach is 2675.28 meters long. At present, this reach is a developed housing. Therefore, it has many artificial elements such as bridge, bank protection.

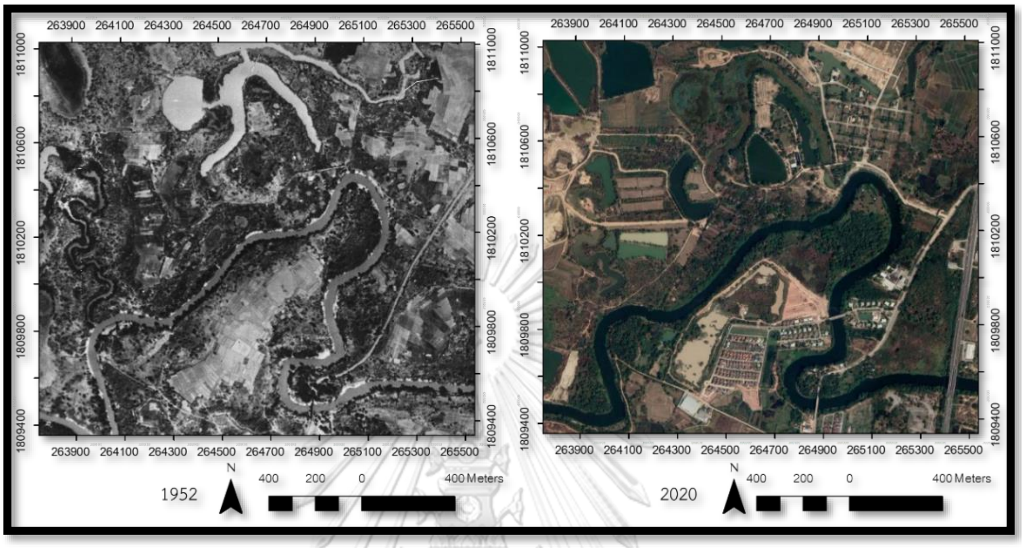

Figure 33 Close up air-photo and satellite image of Reach 10.

4.3.1.11 Detail of Reach 11

Figure 34 shows condition of reach 11 in 1952 and 2020. Reach 11 is straight river that orientates in East-West direction. This reach is 2749 meters long. For artificial elements, this reach has three bridges that cross over the river. Moreover, this reach doesn't find only artificial element but also many disturbance activities. First, paleochannel has been modified to artificial lake. Second, the channel has been modified. Finally, it has activity that pumps water out of river.

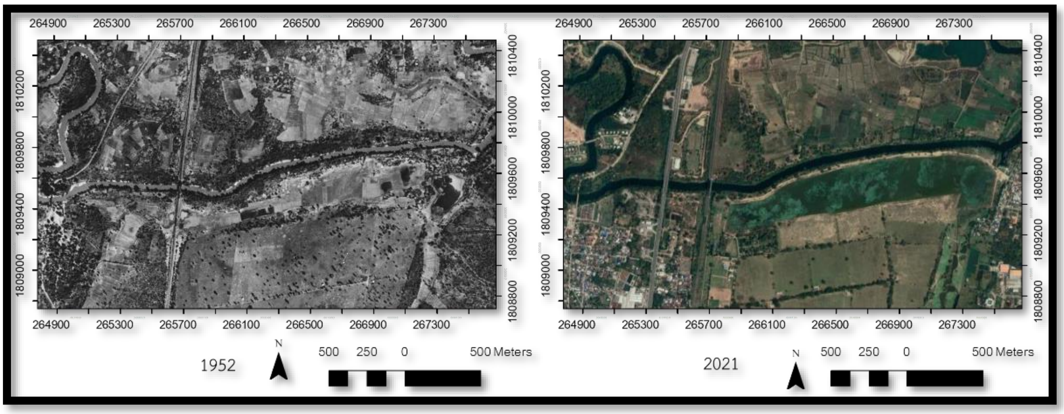

Figure 34 Close up air-photo and satellite image of Reach 11.

4.3.1.12 Detail of Reach 12

Figure 35 shows condition of reach 12 in 1952 and 2020. Reach 12 is meandering river that orientates in North-South direction. This reach is 2706.1 meters long. Many vegetation areas of this reach have been removed.

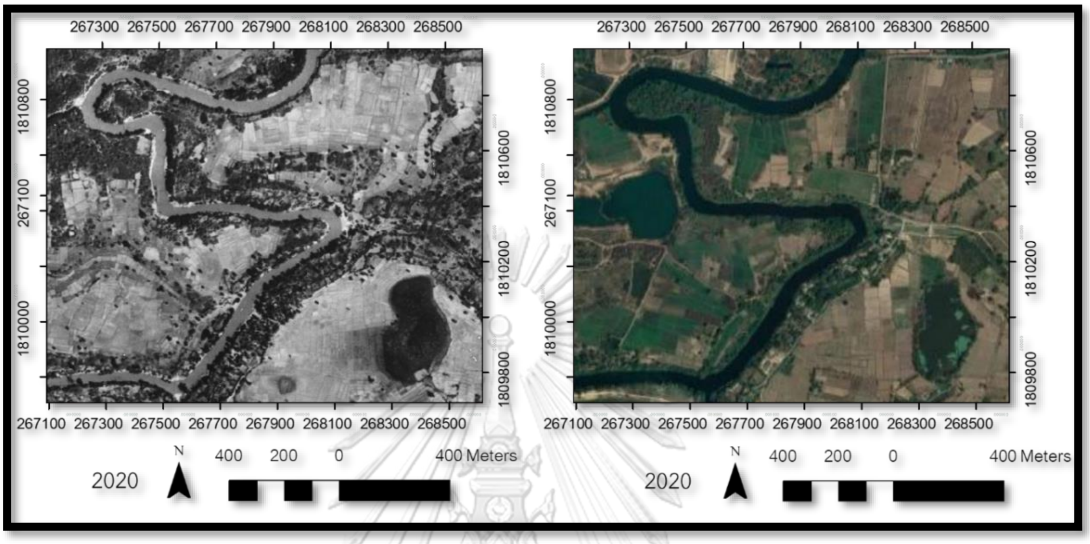

Figure 35 Close up air-photo and satellite image of Reach 12.

4.3.1.13 Detail of Reach 13

Figure 36 shows condition of reach 13 in 1952 and 2020. Reach 13 is meandering river that orientates in East-West direction. This reach is 4794.15 meters long. The vegetation areas of this reach have changed to urban area. It has many artificial elements such as bridge, roads that near the river bank. These roads are one factor that has reduced the potentially erodible corridor of river.

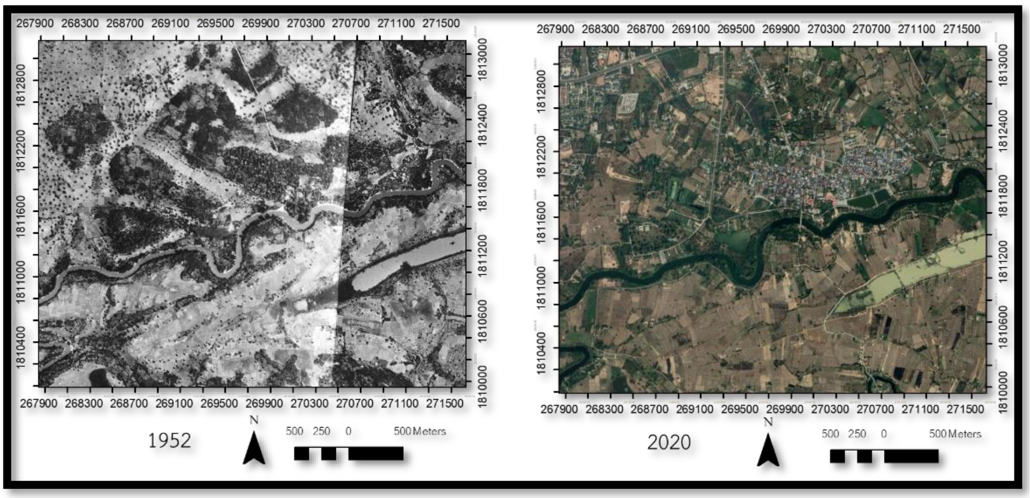

Figure 36 Close up air-photo and satellite image of Reach 13.

4.3.1.14 Detail of Reach 14

Figure 37 shows condition of reach 14 in 1952 and 2020. Reach 14 is meandering river that orientates in Northeast-Southwest direction. This reach is 1695.2 meters long. Many vegetation areas of this reach have been removed. Moreover, it has many roads that near the river bank. These roads are one factor that has reduced the potentially erodible corridor of river.

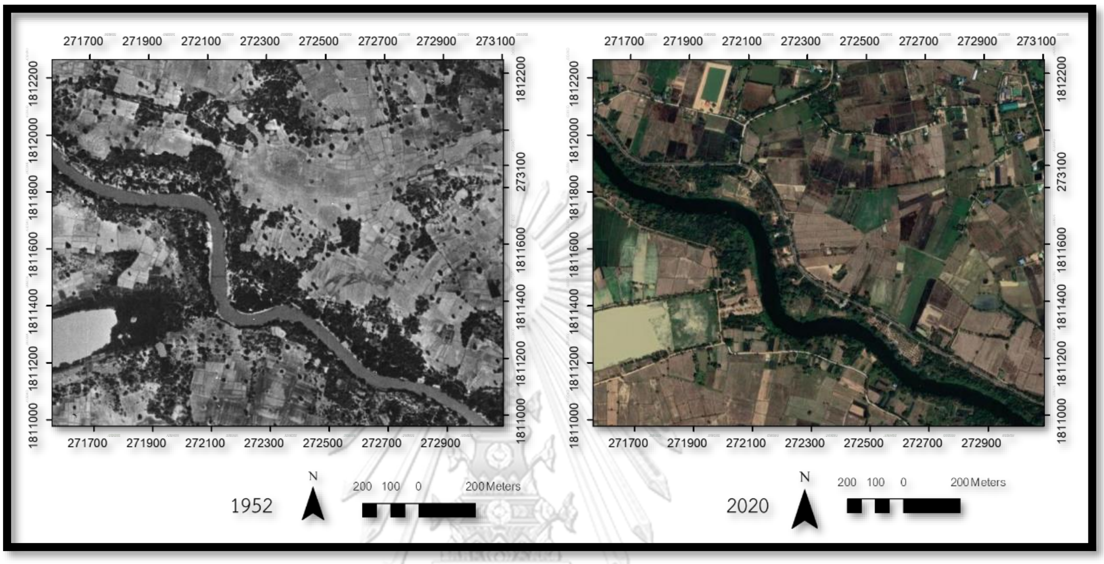

Figure 37 Close up air-photo and satellite image of Reach 14.

4.3.1.15 Detail of Reach 15

Figure 38 shows condition of reach 15 in 1952 and 2020. Reach 15 is meandering river that orientates in East-West direction. This reach is 222.36 meters long. The vegetation area has modified to urban area. Thus, it has some artificial elements such bridge, road that nears the river bank.

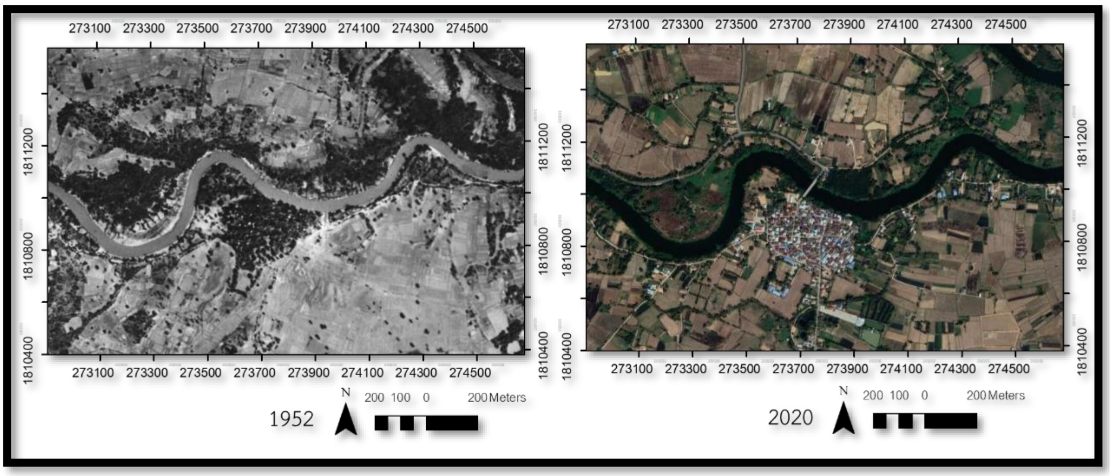

Figure 38 Close up air-photo and satellite image of Reach 15.

4.3.1.16 Detail of Reach 16

Figure 39 shows condition of reach 16 in 1952 and 2020. Reach 16 is a meander neck area that is 7109 meters long. According to the left bank, it has many roads that near the river bank. These roads are one factor that has reduced potentially erodible corridor. Moreover, many vegetation areas have been removed. It has drainage system nears the reach.

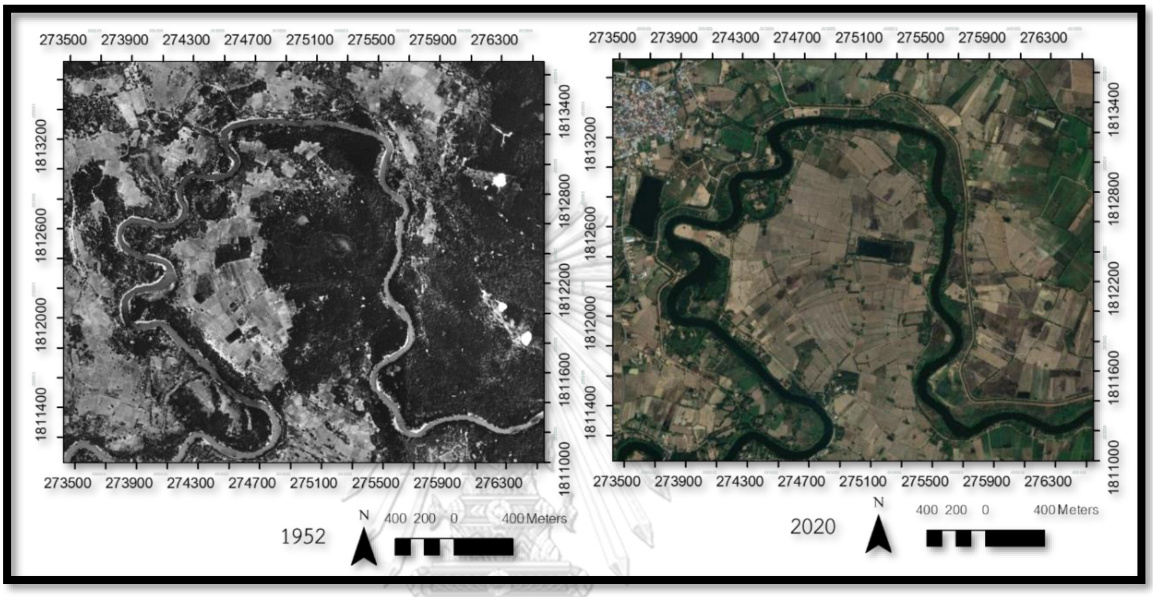

Figure 39 Close up air-photo and satellite image of Reach 16.

4.3.1.17 Detail of Reach 17

Figure 40 shows condition of reach 17 in 1952 and 2020. Reach 17 is the straight river that orientates in East-West direction. This reach is 1610.33 meters long. According to river bank, it has many roads that nears that near the river bank**.**

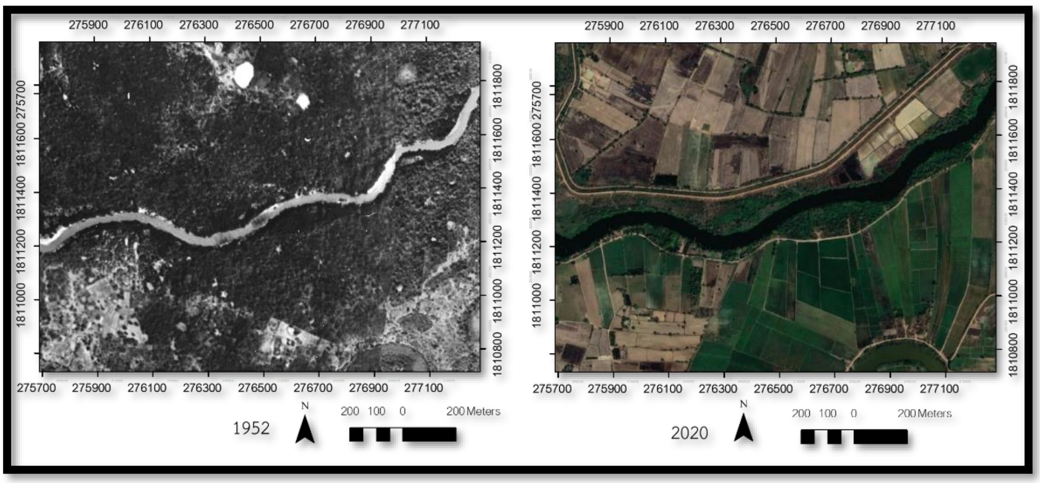

Figure 40 Close up air-photo and satellite image of Reach 17.

4.3.1.18 Detail of Reach 18

Figure 41 shows condition of reach 18 in 1952 and 2020. Reach 18 is the meandering river that orientates in East-West direction. This reach is 2072.63 meters long. Many vegetation areas of this reach have been removed. Moreover, it has drainage system near the reach.

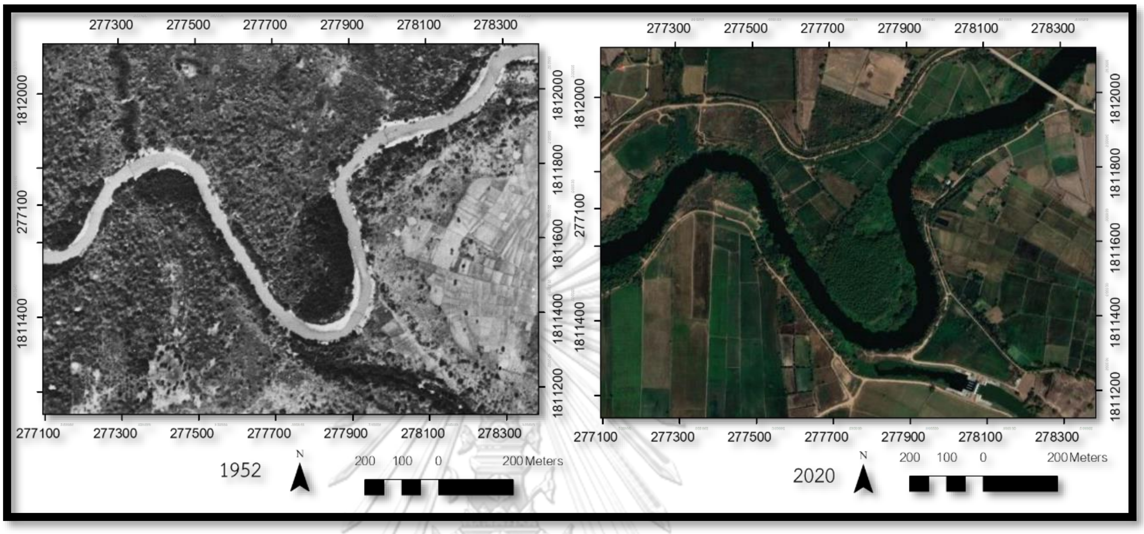

Figure 41 Close up air-photo and satellite image of Reach 18.

4.3.1.19 Detail of Reach 19

Figure 42 shows condition of reach 19 in 1952 and 2020. Reach 19 is the straight river that orientates in East-West direction. This reach is 1396.7 meters long. Many vegetation areas of this reach have been removed.

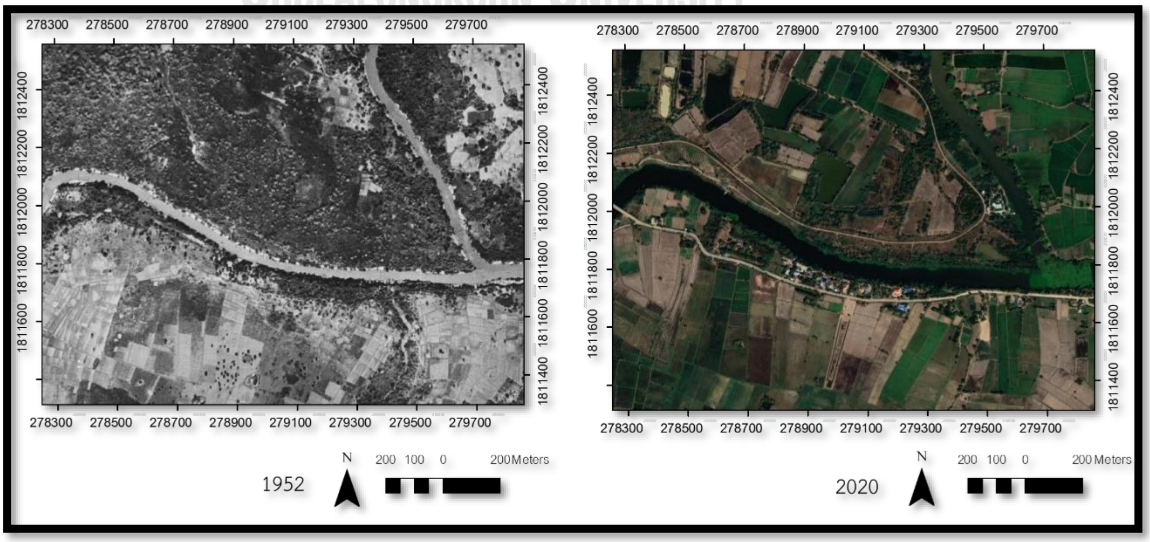

Figure 42 Close up air-photo and satellite image of Reach 19.

4.3.1.20 Detail of Reach 20

Figure 43 shows condition of reach 20 in 1952 and 2020. At present, reach 20 is sinuous river that orientates in Northwest-Southeast. However, this reach was meandering river until 1992. Because this reach has a dam that operated in 1992. This dam causes flow direction of river has been changed. In addition, it has many roads that near the river bank.

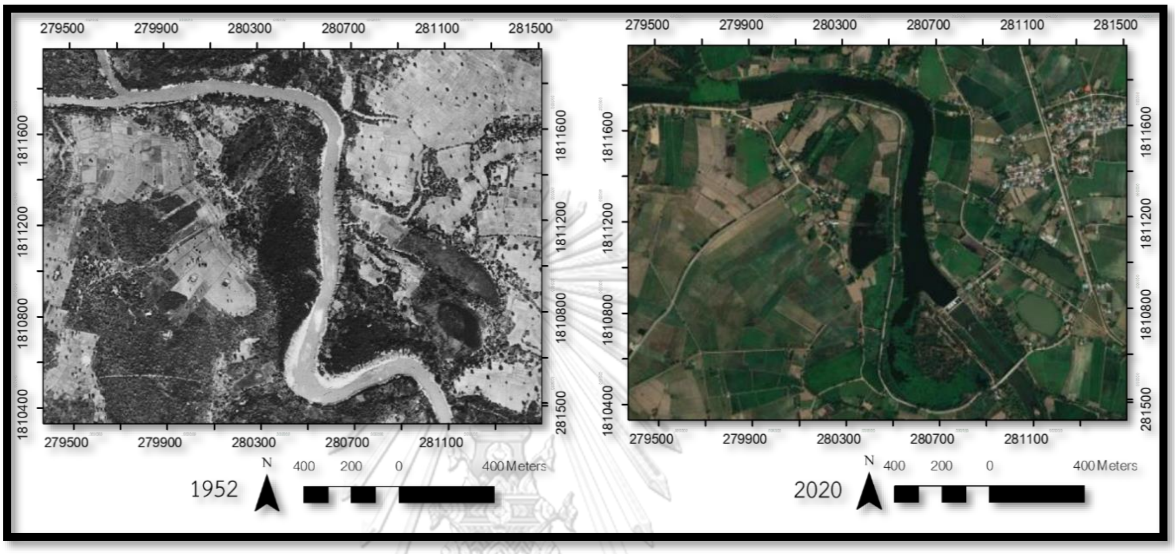

Figure 43 Close up air-photo and satellite image of 20.

4.3.1.21 Detail of Reach 21

Figure 44 shows condition of reach 21 in 1952 and 2020. Reach 21 is a downstream area of dam. This reach is meandering river that orientates in North-South direction. For river length, this reach is 3704.69 meters long. This reach has creek that may be a one of sediment source of Chi river. For artificial element, this reach has one bridge that crosses over the river.

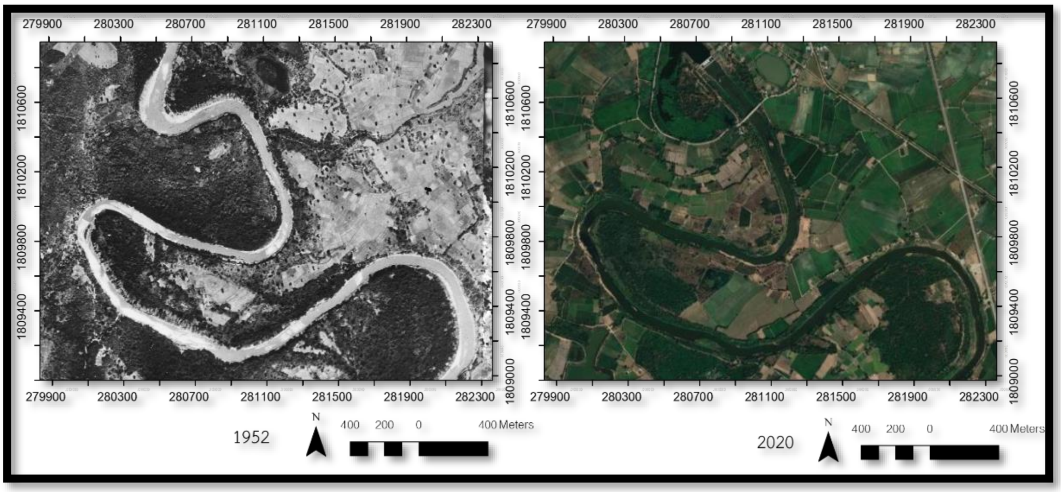

Figure 44 Close up air-photo and satellite image of Reach 21.

4.3.1.22 Detail of Reach 22

Figure 45 shows condition of reach 22 in 1952 and 2020. Reach 22 is a meandering river that orientates in Northeast-Southwest direction. This reach is 5077.35 meters long. Vegetation area of this reach has changed to urban area. In addition, it has road that nears the bank.

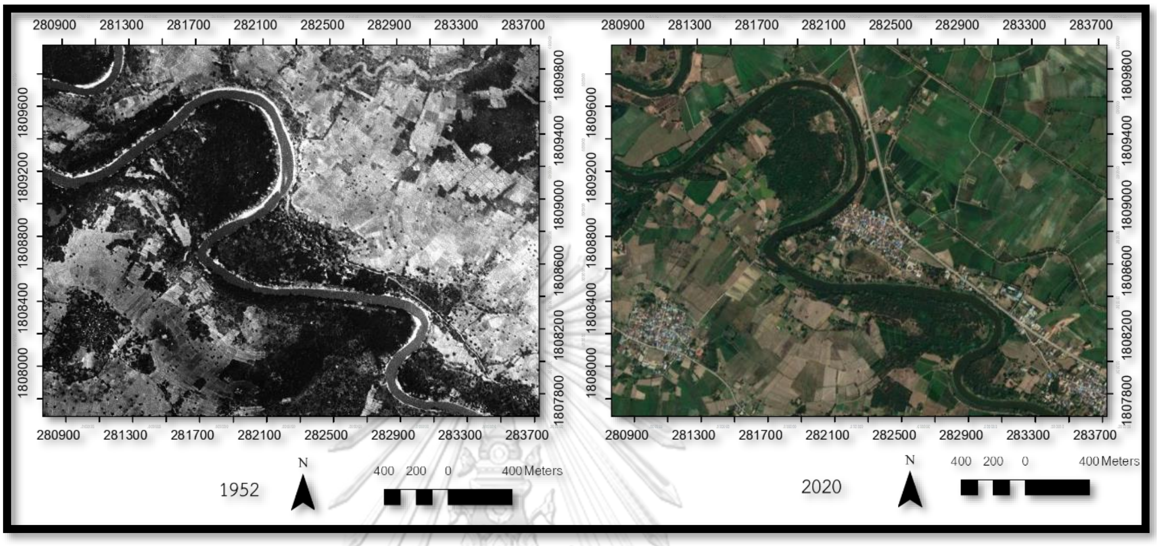

Figure 45 Close up air-photo and satellite image of Reach 22.

4.3.1.23 Detail of Reach 23

Figure 46 shows condition of reach 23 in 1952 and 2020. Reach 23 is straight river that orientates in East-West direction. This reach is 1346.22 meters long. For artificial element, it has one bridge that cross over the river. Moreover, many vegetation areas have been changed to urban area.

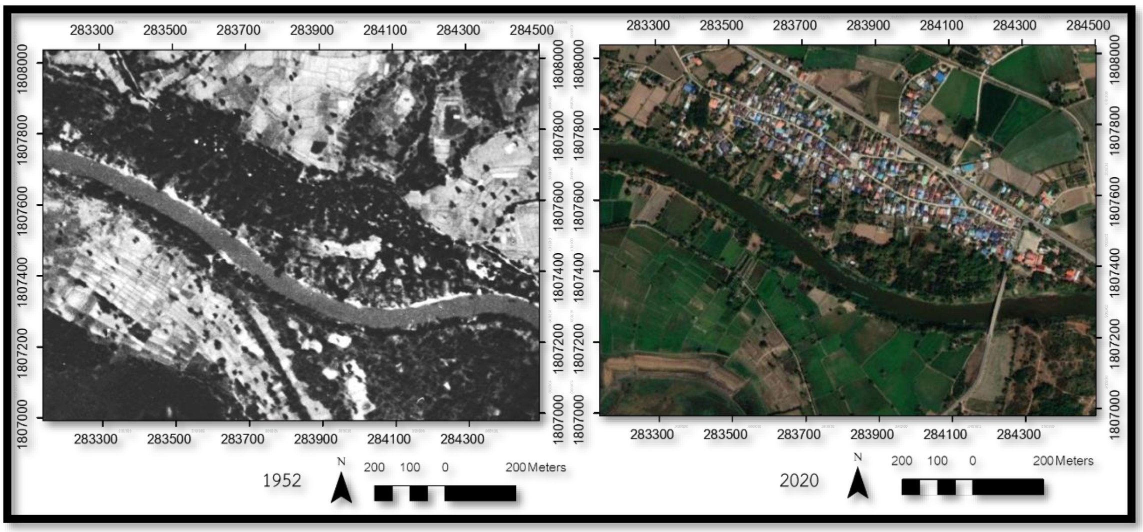

Figure 46 Close up air-photo and satellite image of Reach 23.

4.3.1.24 Detail of Reach 24

Figure 47 shows condition of reach 24 in 1952 and 2020. Reach 24 is meandering river that orientates in East-West direction. This reach is 3138.26 meters long. For artificial element, this reach has a bank protection. Vegetation area has been removed. Moreover, it has river sand mining in this reach.

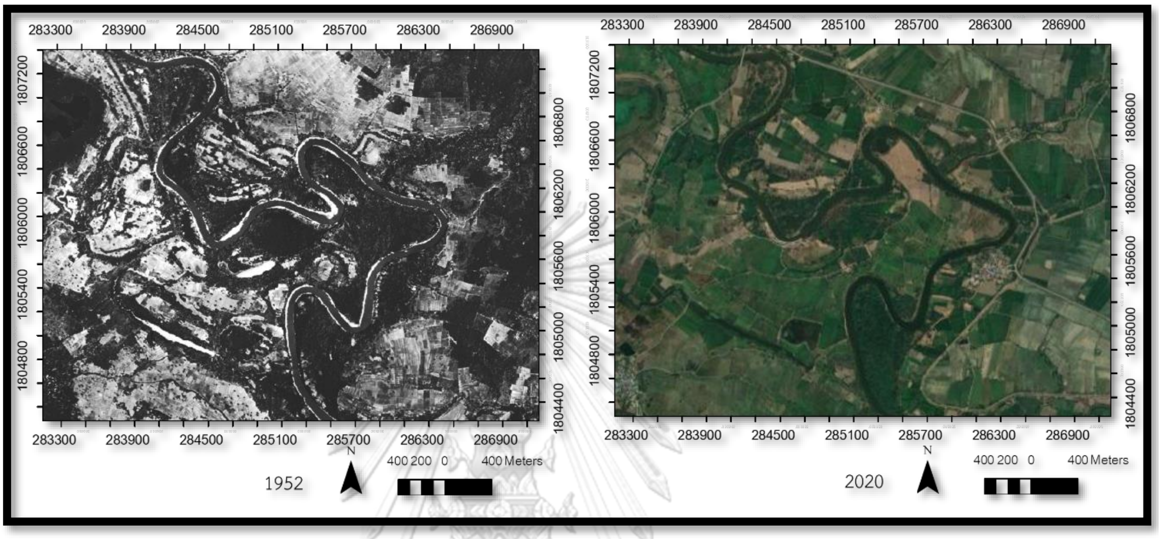

Figure 47 Close up air-photo and satellite image of Reach 24.

4.3.1.25 Detail of Reach 25

Figure 48 shows condition of reach 24 in 1952 and 2020. Reach 25 is straight river that orientates in Northwest-Southeast direction. This reach is 2188.23 meters long. Some vegetation areas have been changed to urban area.

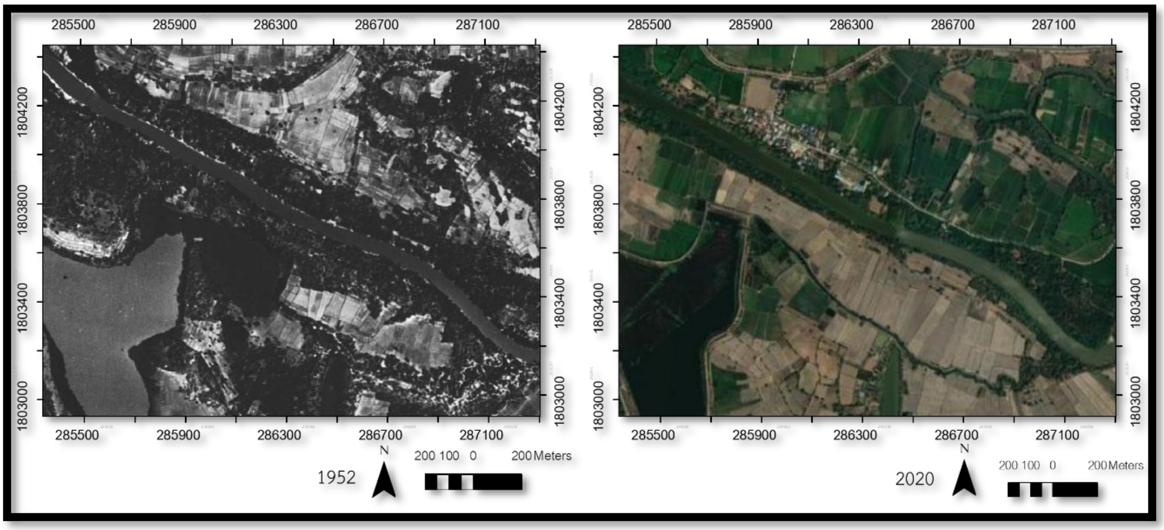

Figure 48 Close up air-photo and satellite image of Reach 25.

4.4 Geomorphic Index

This thesis uses 3 geomorphic indices: Sinuosity Index, Channel Width, and Migration rates. These indices were measured by remote sensing techniques in the dry season in 5 different periods: 1952, 1988, 1992, 2002, and 2020. The sinuosity index was measured in each reach scale that was divided. In comparison, Channel width and migration rate were measured for every 100 meters length of a river. Thus, it has 690 stations that were measured channel width and migration rate. Also, this chapter compares the erosion area and deposition area of the Chi River between 2006 and 2020.

4.4.1 Sinuosity Index

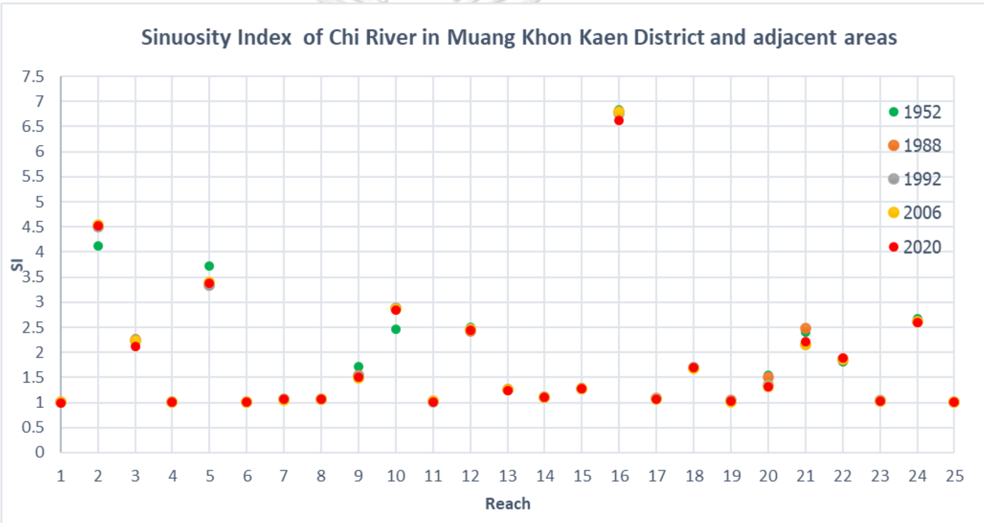

Figure 49 The graph of Sinuosity index of Chi river in Muang Khon Kaen district and adjacent areas.

Figure 49 shows the graph of the sinuosity index measured in 5 different periods in each reach. According to the graph, the Y-axis is the Sinuosity index value, and the X-axis is the number of reaches. The sinuosity index value varies from just 1.005 to 6.82. However, it has only 6 reaches that have significant changes of the sinuosity index value. First, reach, the Sinuosity index value of reach 2 increased from 2.11 in 1952 to 4.52 in 2020. Next, the Sinuosity index value of reach 5 decreased from 3.71 in 1952 to 3.37 in 2020. Next, the Sinuosity index value of reach 16 decreased from 6.82 in 1952 to 6.62 in 2020. Finally, the Sinuosity index value of reach 20 and 21 dramatically decreased from 1.50 in 1988 to 1.31 in 1992 and from 2.47 in 1988 to 2.21 in 1992. The dramatic alterations of the sinuosity index of reach 20 and 21 between 1988 to 1992 were caused by constructing an irrigation dam that has changed the Chi river's flow direction.

4.4.2 Channel Width

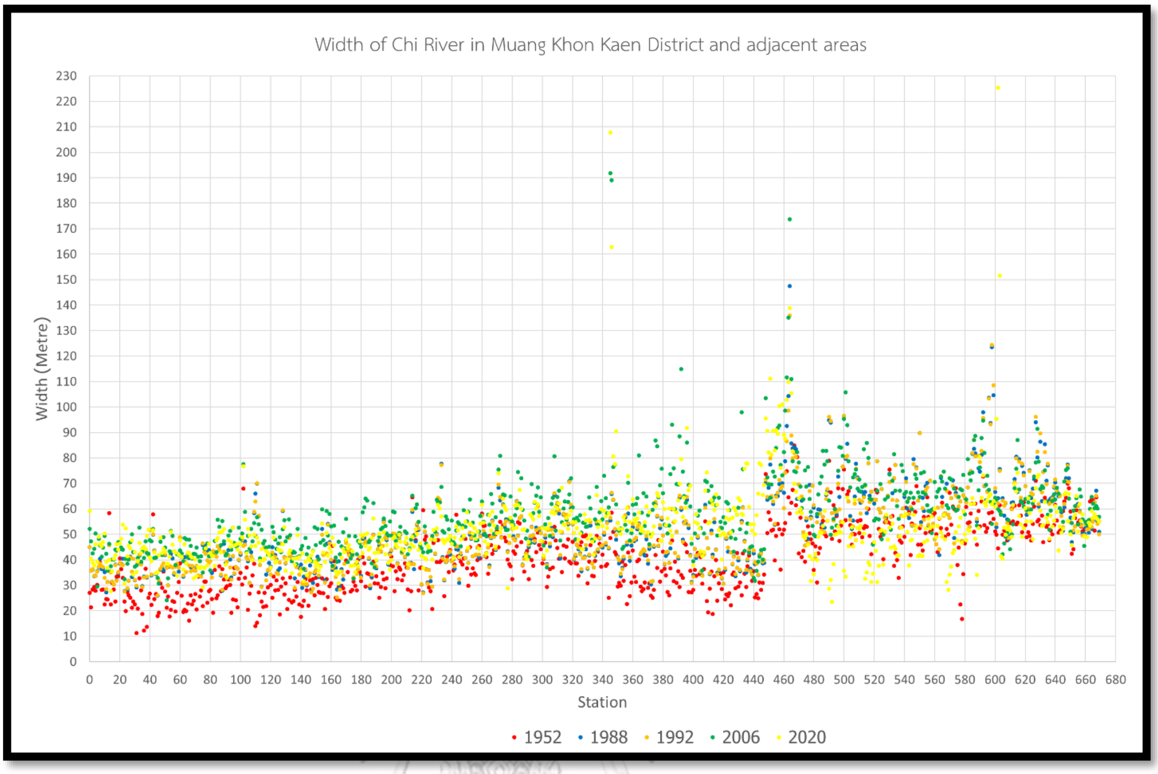

Figure 50 The graph of channel width of Chi river in Muang Khon Kaen district and adjacent areas.

Figure 50 shows the graph of Channel width measured in the dry season in 5 different periods: 1952, 1988, 1992, 2006, and 2020. According to the graph, Y-axis is the Channel width was measured in meters and the X-axis is the station. It can be seen that channel width varies from just 11.1 meters to more than 200 meters. Overall, the Width that was measured in 2020 is wider than the Width that was measured in 1952. It has significant changing width in 4 stations: station 345 and 392 in reach 16, station 464 in reach 20, and station 602 in reach 24.

4.4.3 Widening rate of Channel width of Chi river

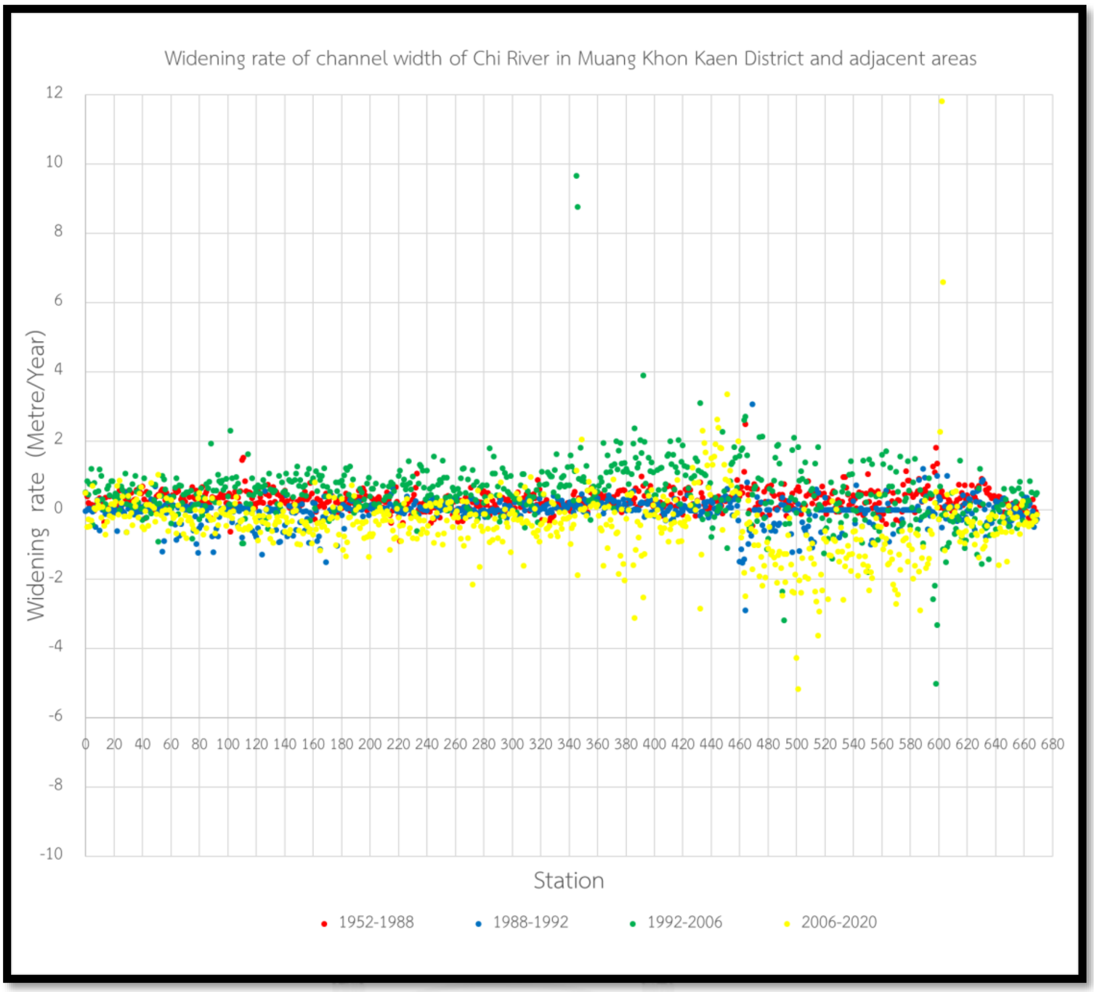

Figure 51 The graph of widening rate of Chi river in Muang Khon Kaen district and adjacent areas.

Figure 51 shows the graph of widening rate that was measured in 4 different periods:1952-1988, 1988-1992, 1992-2006, 2006-2020. According to the graph, the X-axis is the station, and the Y-axis is widening rate that was measured in meters per year. Basically, widening rate is more than 1, which means the channel is wider than in the past. However, widening rate is less than 1, which means the channel is narrower than in the past. It can be seen that widening rate varies from -5.17 meters per year to 11.08 meters per year. It has a significant 4 widening rate. First, the widening rate at station 345 in 1992 - 2006 has a widening rate of 9.66 meters per year. Second, the widening rate at station 501 in 2006 – 2020 has a widening rate of -5.17 meters per year. Third, the widening rate at station 598 in 1992 – 2006 has a widening rate of -5.01 meters per year. Finally, the widening rate at station 602 in 2006 – 2020 has a widening rate of 11.8 meters per year.

4.4.4 Migration Rate

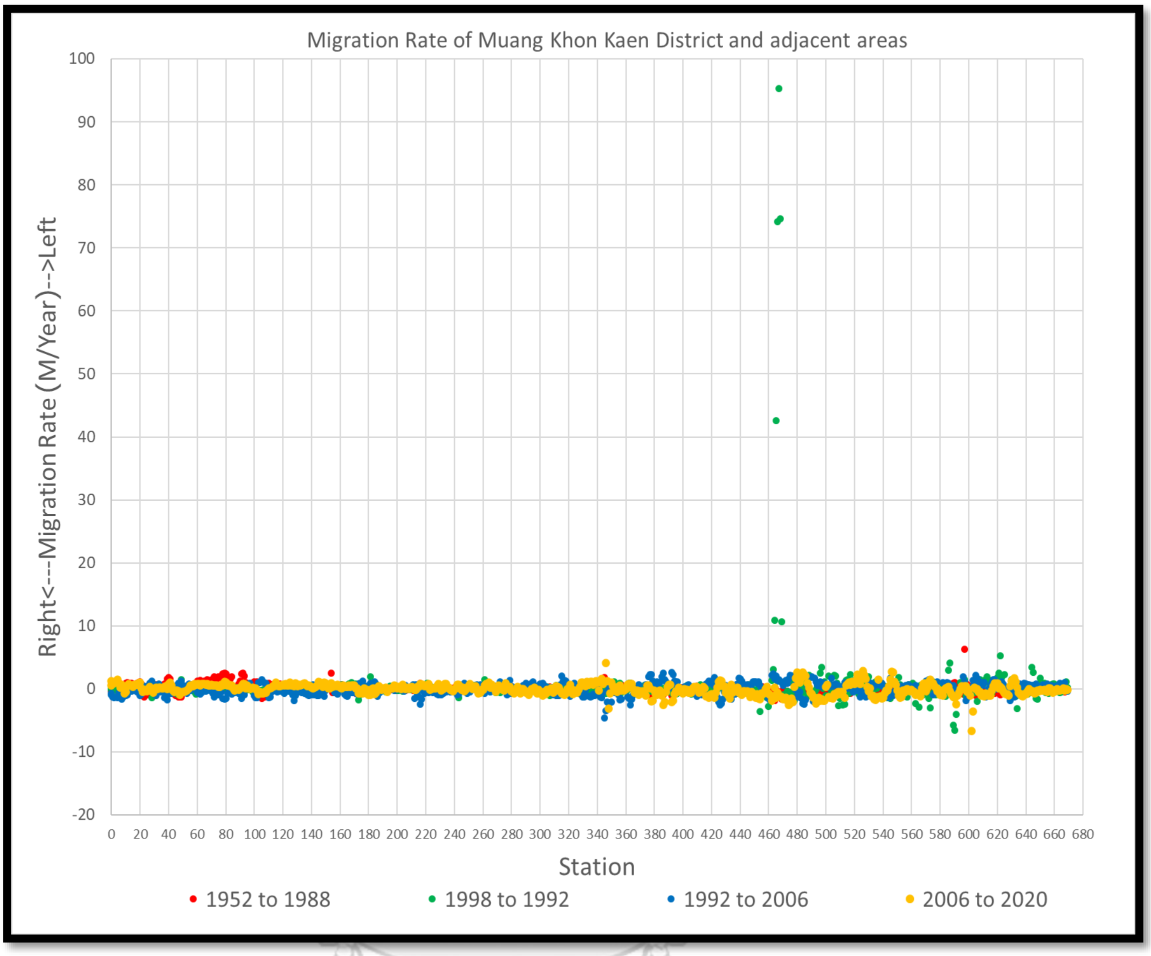

Figure 52 The graph of migration rate of Chi river in Muang Khon Kaen district and adjacent areas.

The migration rate was calculated by the changing of a mid-channel in each period. Figure 52 Shows the graph of the migration rate of the Chi river in 4 different periods: According to the graph, X-axis is a station that was measured migration rate, and Y-axis is the migration rate that was measured in meter per year. For Y-axis, if the migration rate is more than 0, it means mid-channel migrates to the left side (observed in direction upstream to downstream). On the other hand, if the migration rate is less than 0, it means mid-channel migrates to the right side (observed in direction upstream to downstream). It can be seen from figure 4.X that it has an anomaly migration rate from 1988 to 1992 at station 467 in reach 20 was more than 90 meters per year while another value was less than 10 meter per year. The migration rate of station 467 from 1988 to 1992 was an anomaly because it had constructed a dam from Royal Irrigation Department between 1988 to 1992. This dam didn't only effect on Channel planform but also the migration rate.

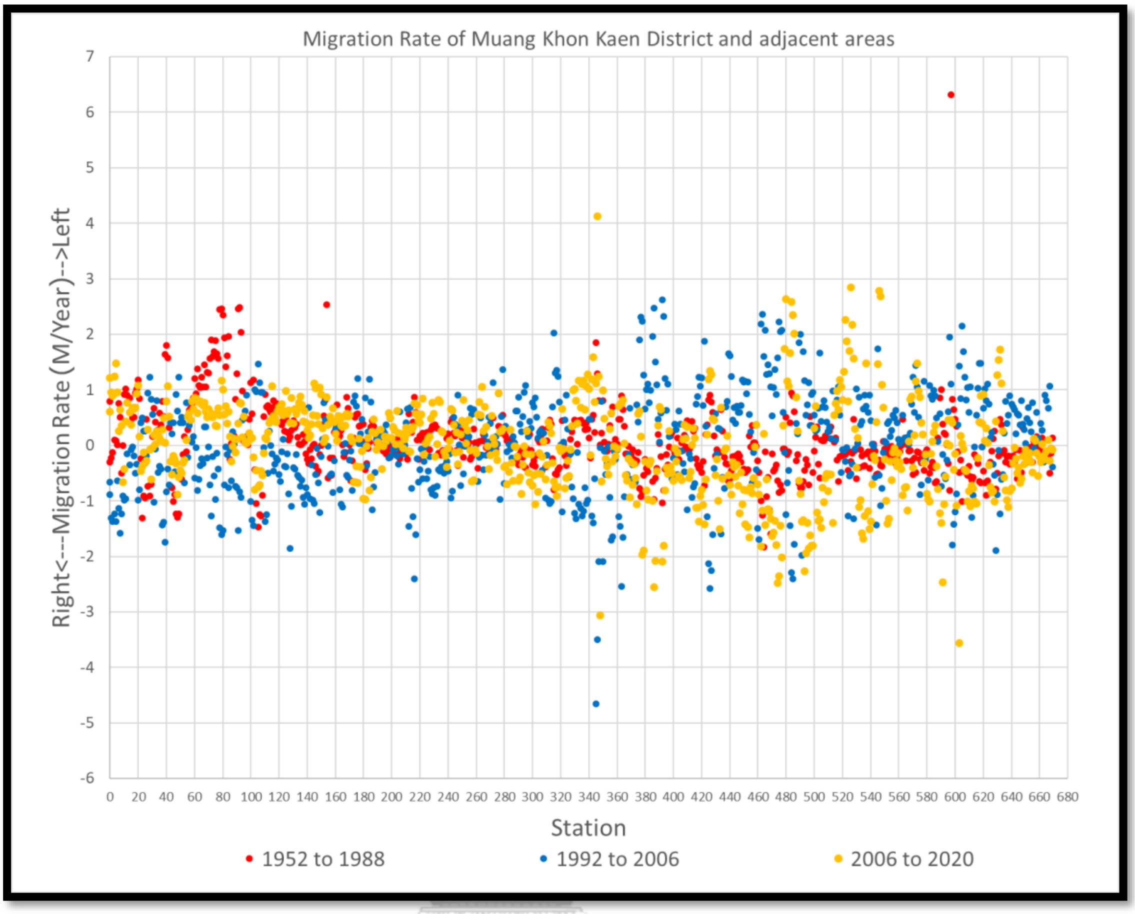

Figure 53 The graph of migration rate of Chi river in Muang Khon Kaen district and adjacent areas in three periods.

Figure 53 shows the graph of migration rate of Chi river in 3 different periods: 1952 to 1988, 1992 to 2006, and 2006 to 2020. This graph removes the migration rate from 1988 to 1992 because this period gives anomaly value. The component of this graph is similar to the previous migration rate graph. The range of migration rate of a new graph is narrower than the previous graph that ranges from -6.44 meter per year to just 4.12 meter per year. Overall, the migration rate from 2006 to 2020 was higher than in another period. According to the graph, it has 5 areas that have a significant migration rate. First, reach 4 and reach 5 have significant rates from station 70 to 85 in 1952 to 1988. Second, reach 16 has significant migration rates during 2006 to 2020 from station 345 to station 386. Third, reach 21 has significant migration rates during 2006 to 2020 from station 467 to station 484 in period 2006 to 2020. Fourth, reach 22 has significant migration rates during 2006 to 2020 from station 527 to 547. Finally, reach 24 has significant migration rates during 2006 to 2020 from station591 to 602. From field survey in September 2020, it found that reach 24 has river sand mining operated after 2006.

4.4.5 Erosion area and Deposition area between 2006 and 2020

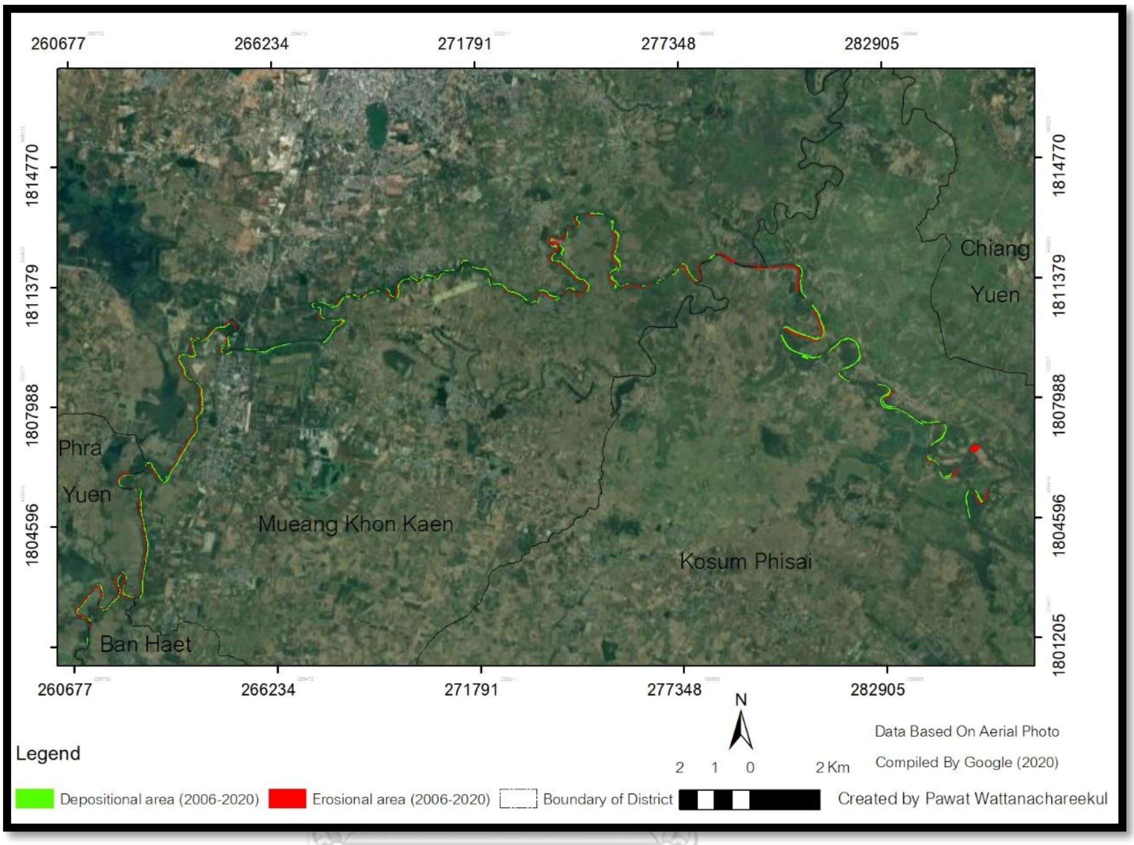

Figure 54 The erosion area and deposition area between 2006 and 2020 in Muang Khon Kaen district and adjacent areas.

It can be seen from the migration rate that the migration rate from 2006 to 2020 is higher than in another period. A comparison of erosional area and depositional area between 2006 and 2020 will help interpret data with changing rate of channel width and migration rate. Figure 54 shows the erosion area and deposition area of the Chi river between 2006 and 2020 with 2 symbols: red color that means erosion area, and green color that means deposition area.

4.5 Hydromorphological condition

The Morphological Quality Index (MQI) was chosen for assessing hydro-morphological conditions in 2020 that revealed the level of artificial and hydro-morphological alteration. The MQI consisted of three elements: artificiality, channel adjustment, and geomorphic functionality. First, artificiality evaluates the number of artificial elements and intervention processes. Next, channel adjustment evaluates the degree of alteration of the channel river. Finally, geomorphic functionality evaluates whether or not an artificial element and channel adjustment alter the river process and morphological conditions. These topics are evaluated in terms of percentage (from 0 to 100). Basically, in case that percentage equals 100, it means this area has maximum alteration. On the other hand, if the percentage equals 0, it means this area has no alteration.

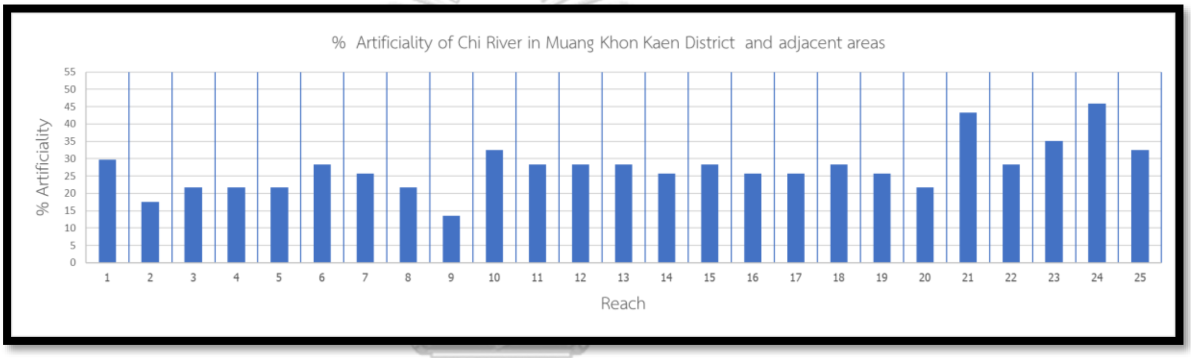

Figure 55 The graph the percentage of artificiality of Chi river in Muang Khon Kaen District and adjacent areas.

Figure 55 shows the graph of the percentage of artificiality of Chi river in Muang Khon Kaen district and adjacent areas. Y-axis is the percentage of artificiality while X-axis is reach. According to the graph, it has only four reaches with the percentage of artificiality more than 30 %. These reaches are reach 10, reach 21, reach 23 and reach 24 that have score 32.43%, 43.24 %, 31.13% and 45.94 %, respectively. First, reach 10, has many alterations in land use and land cover. It has developed from vegetation area to developed housing constructed artificial elements such as bank protection and bridge. Next, reach 21 is the downstream area of the dam. Next, reach 23 has removed many vegetation riparian area that is one of bed substrate. Finally, reach 24 has bank protection in the area. Moreover, it has river sand mining that removes sediment from the river in this area.

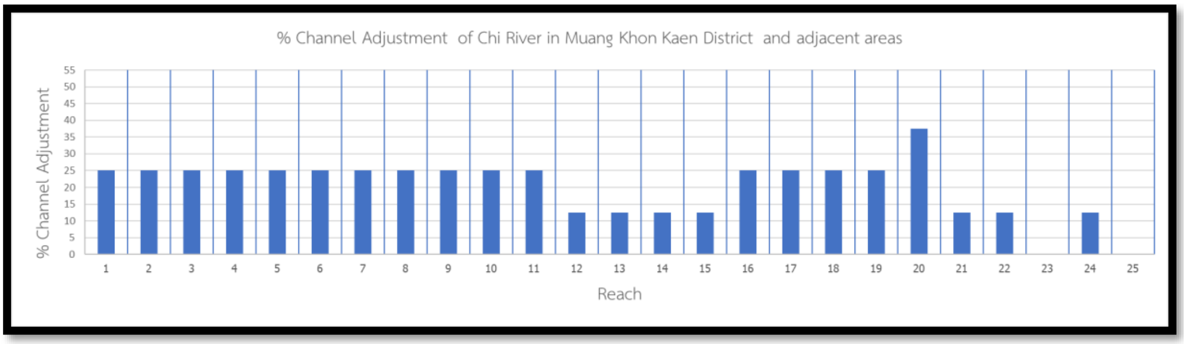

Figure 56 The graph the percentage of channel adjustment in Muang Khon Kaen District and adjacent areas.

Figure 56 shows the graph of the percentage of channel adjustment of Chi River in Muang Khon Kaen district and adjacent areas. Y-axis is the percentage of channel adjustment while X-axis is reach. Overall, almost reach has a percentage of channel adjustment less than 25 % because almost reach has the only alteration in channel width. However, reach 21 is the only reach that has an alteration in channel planform. Because this area has a dam that has altered the flow direction of the channel. Thus, the planform of the river has changed from meandering to the straight river. Moreover, it can be seen that it has two reaches that have the percentage of channel adjustment equals 0. These reaches are reach 23 and reach 25 because this area has a limited adjustment in channel width that has less than 15 % since 1952.

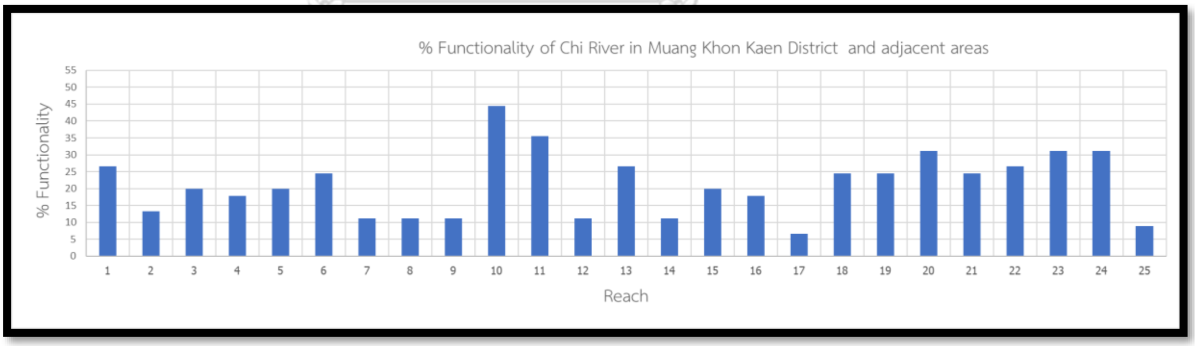

Figure 57 The graph the percentage of functionality in Muang Khon Kaen District and adjacent areas.

Figure 57 shows the graph percentage of functionality of Chi river in Muang Khon Kaen district and adjacent areas. Y-axis is the percentage of functionality while X axis is reach. Overall, it has 5 reaches that have a percentage of functionality of more than 30 %. These reaches are reach 10, reach 11, reach 20, reach 23 and reach 24 that have score 44.44 %, 35.55 %, 31.11%, 31.11 % and 31.11 %, respectively. First, reach 10, floodplain aquatic zone in this area has been modified. Moreover, the vegetation zone in the riparian area has been modified. Next, reach 11, this area has an alteration in the riparian zone that abandoned paleo channel has been modified to the artificial lake. Moreover, the channel in this area has been modified by digging. Next, reach 20 is the upstream area of the irrigation dam. Many vegetation area of reach 20 has removed. Finally, reach 23 and reach 24, these areas have many structures such bridge, bank protection that affects the diversity of geomorphology.

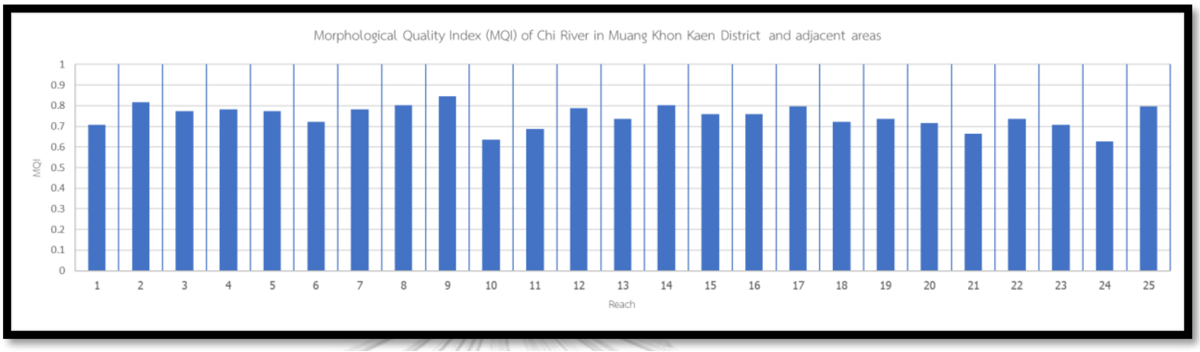

Figure 58 The graph of the MQI score of Chi river in Muang Khon Kaen District and adjacent areas.

Figure 58 shows the graph of the MQI score of Chi river in Muang Khon Kaen District and adjacent areas. Y-axis is the MQI score, while X-axis is reach. According to the graph, the MQI score ranges from 0.79 to 0.63. Thus, it can divide into two morphological quality classes: Good class and Moderate class. Almost all reaches are categorized in a good class, but it has only 4 reaches categorized in moderate class (MQI score below 0.70). These classes are reach 10, reach 11, reach 21 and reach 24 with MQI score of 0.63, 0.68, 0.66, and 0.64, respectively.

4.6 Asymmetry of Channel

Asymmetry indices of the channel's asymmetry was analyzed based on Knighton (1981), and Das and Islam (2018) from cross-sectional shape data. The cross-section data were collected every 10 meters in horizontal distance, and the elevation of the cross-sectional shape of the channel is normalized elevation. Basically, it means that elevation at 0 meters is the deepest point of the channel. This thesis collected cross-sectional shapes of the Chi river from 5 different bridge in Chi river (Figure 59) in October 2020. First, station 1 is the Tha Phra bridge in Khon Kaen that locates in reach 6. Second, station 2 is Tha Raj Chai Sri that locates in reach 13. Third, station 3 is Ladawan bridge that locates in reach 18. This station is the upstream area that nears the dam. Fourth, station 4 is Ban Kuichaug bridge that locates in reach 21. This station is downstream that nears the dam. Also, Royal Irrigation Department collected the Chi river's cross-sectional shape at this bridge in January 2020. So, this part compares the cross-sectional shape of the channel between January 2020 and October 2020. Fifth, station 5 is Nong Phue-Phon Ngam that locates reach 23.

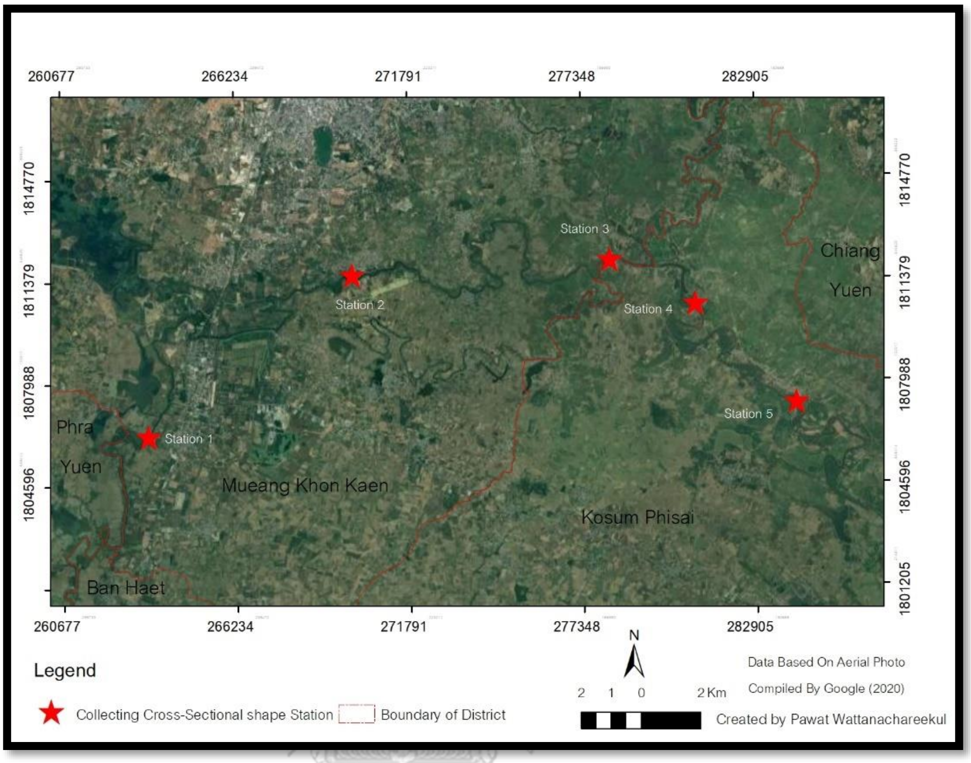

Figure 59 The locations of 5 different bridge that collecting cross-sectional data.

4.6.1 Detail of cross-sectional shape

The channel cross-sectional shape has 5 components. First, redline is the normalized elevation of the channel. The elevation at 0 meter represents the deepest point of each channel. Second, Blueline is a top surface of a water body in a channel. Third, the yellow line is the centerline of the channel width. Fourth, the orange line is the median area line of the channel. Fifth, the green line is the max depth line of the channel.

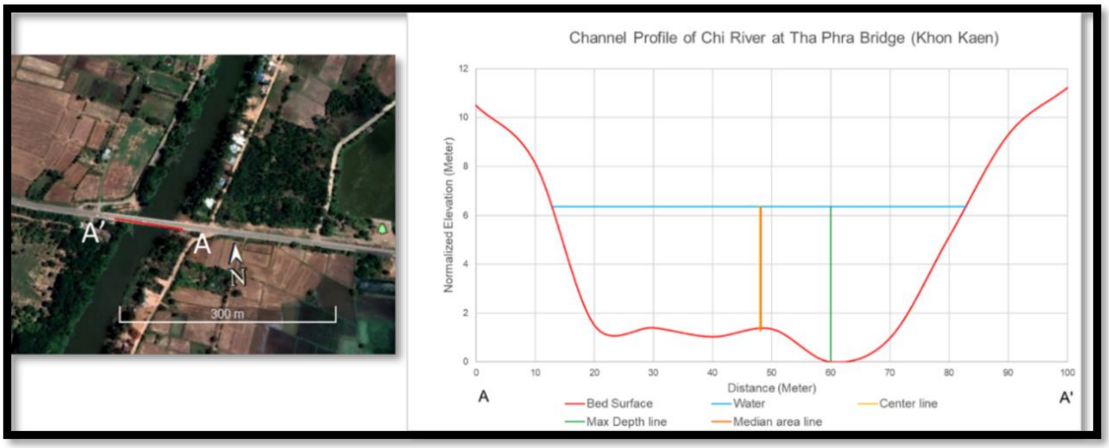

Figure 60 The cross-section of Chi river at station 1.

Figure 60 shows the cross-sectional of Chi river a river at station 1. X-axis is horizontal distance while Y-axis is normalized elevation. This section's channel width is 70 meters, while the area of a cross-sectional shape is 319.144 square meters. For depth, this section's maximum depth is 6.35 meters from the water's top surface, while the average depth is 4.55 meters from the top surface of the water, while the average depth is 4.55 meters from top surface of the water. According to the graph, it can be seen that the median area line is close together with the centerline. However, the maximum depth line nears the right bank. It far from right bank 23 meters.

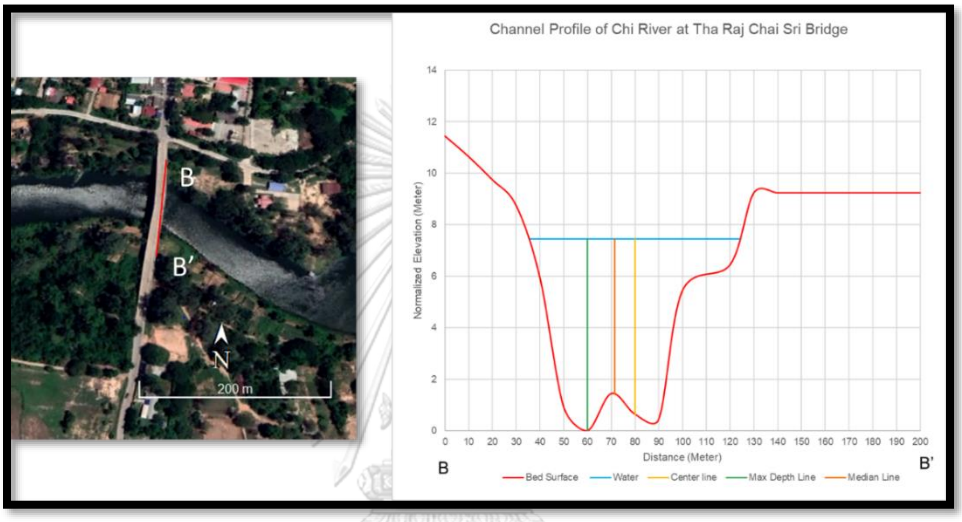

Figure 61 The cross-section of Chi river at station 2.

Figure 61 shows the cross-sectional of Chi river at station 2. X-axis is horizontal distance while Y-axis is normalized elevation. This section's channel width is 88 meters, while the area of the cross-sectional shape is 390.1 square meters. For depth, this section's maximum depth is 7.44 meters from the top surface of the water, while the average depth is 4.43 meters from the top surface of the water. According to the graph, it can be seen that the median area line and the maximum depth line skew in the left direction from the centerline. The maximum depth is far from the left bank 20 meters while the median area line is far from the left bank 31.3 meters.

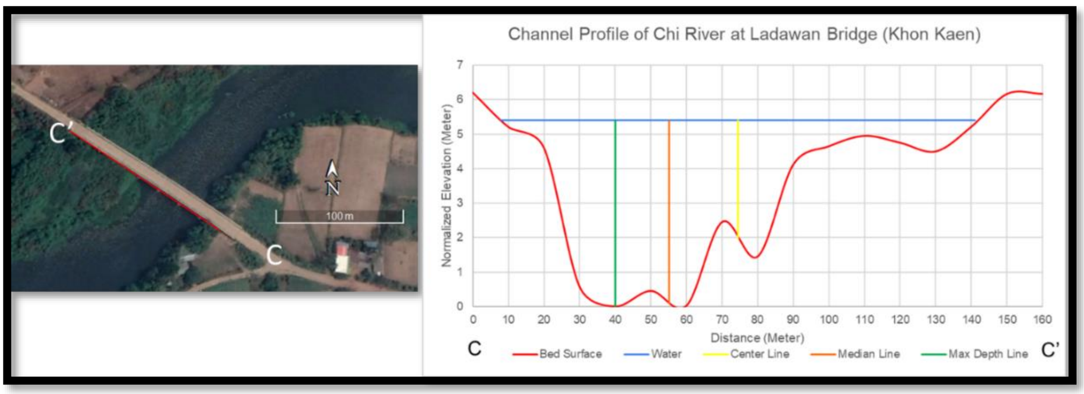

Figure 62 The cross-section of Chi river at station 3.

Figure 62 shows the cross-sectional of Chi river at station 3. X-axis is horizontal distance while Y-axis is normalized elevation. This section's channel width is 133 meters, while the cross-sectional shape area is 325.14 square meters. For depth, this section's maximum depth is 5.4 meters from the water's top surface, while the average depth is 2.44 meters from the top surface of the water. According to the graph, it can be seen that the median area line and the maximum depth line skew in the left direction from the centerline. The maximum depth is far from the left bank 32 meters, while the median area line is far from the left bank 47.2 meters.

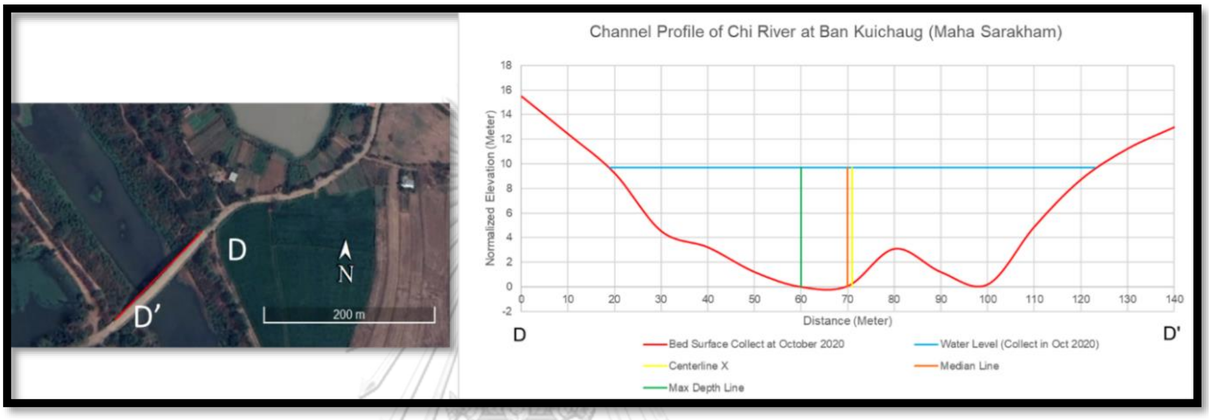

Figure 63 The cross-section of Chi river at station 4.

Figure 63 shows the cross-sectional of Chi river at station 4. X-axis is horizontal distance while Y-axis is normalized elevation. This section's channel width is 104 meters, while the cross-sectional shape area is 696.04 square meters. For depth, this section's maximum depth is 9.68 meters from the water's top surface, while the average depth is 8.37 meters from the top surface of the water. According to the graph, it can be seen that the median area line and the maximum depth line skew in the left direction from the centerline. The maximum depth is far from the left bank 43.5 meters.

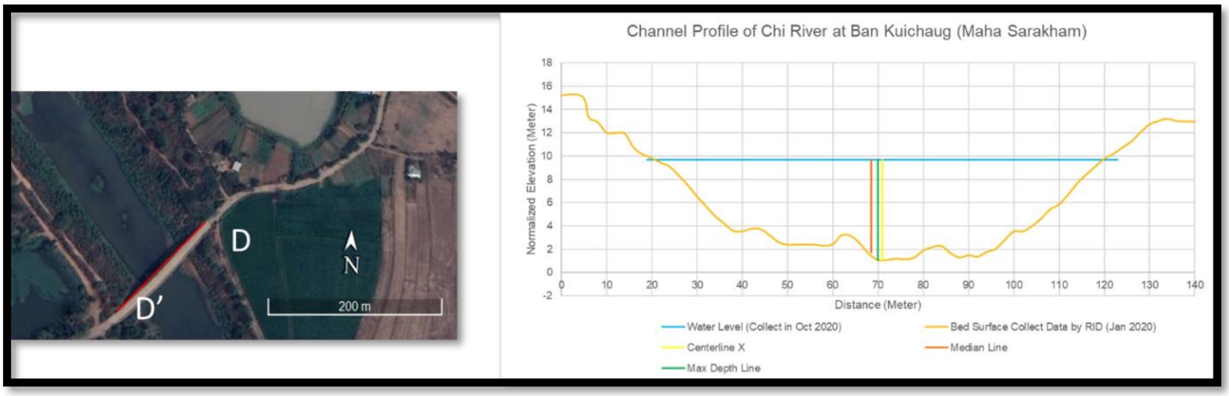

Figure 64 The cross-section of Chi river at station 4 that was collected in January 2020.

Also, this station was collected data by Royal Irrigation Department in January that is shown in Figure 64. This cross-section area that bases on the water level from November 2020 is 580.40 square meters. According to the graph, it can be seen that the median area line and the maximum depth are close to the centerline.

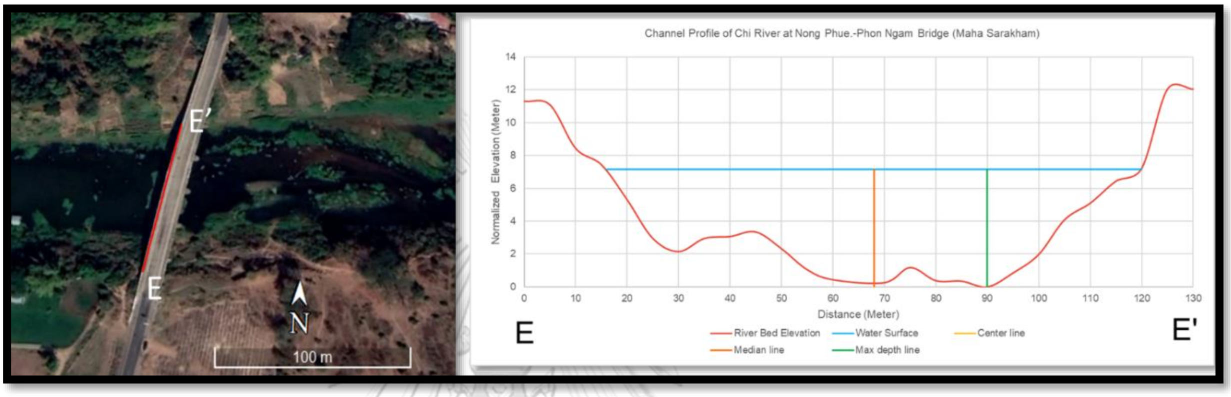

Figure 65 The cross-section of Chi river at station 5.

Figure 65 shows the cross-section of Chi river at station 5. X-axis is horizontal distance while Y-axis is normalized elevation. This section's channel width is 104 meters, while the cross-sectional shape area is 479.80 square meters. For depth, this section's maximum depth is 7.14 meters from the top surface of the water, while the average depth is 4.47 meters from the top surface of the water. According to the graph, it can be seen that the median area line is close together with the centerline. However, the maximum depth line nears the right bank that is far from the right bank 23 meters.

4.6.2 Asymmetry index from Knighton (1981)

4.6.2.1 A* index

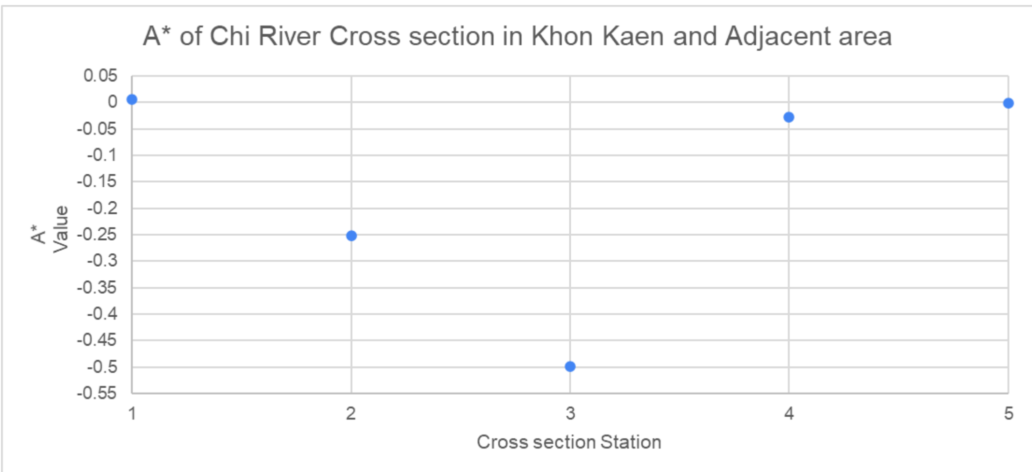

Figure 66 The graph of A* of Chi river cross-section in Chi river in Muang Khon Kaen district and adjacent areas.

Figure 66 shows the graph of A* value. X-axis is the station that was collected cross-sectional shape of the channel, and Y is A* value. According to the graph, it can be seen that the most asymmetry channel is station 3 that has A* value of -0.5. The second asymmetry channel is station 4 that has A* value of -0.25. The third asymmetry channel is station 4 that has A* value of -0.025. Cross-sections from station 1 and station 5 are considered symmetry channels because their A* value is very close to 0.

4.6.2.2 A1

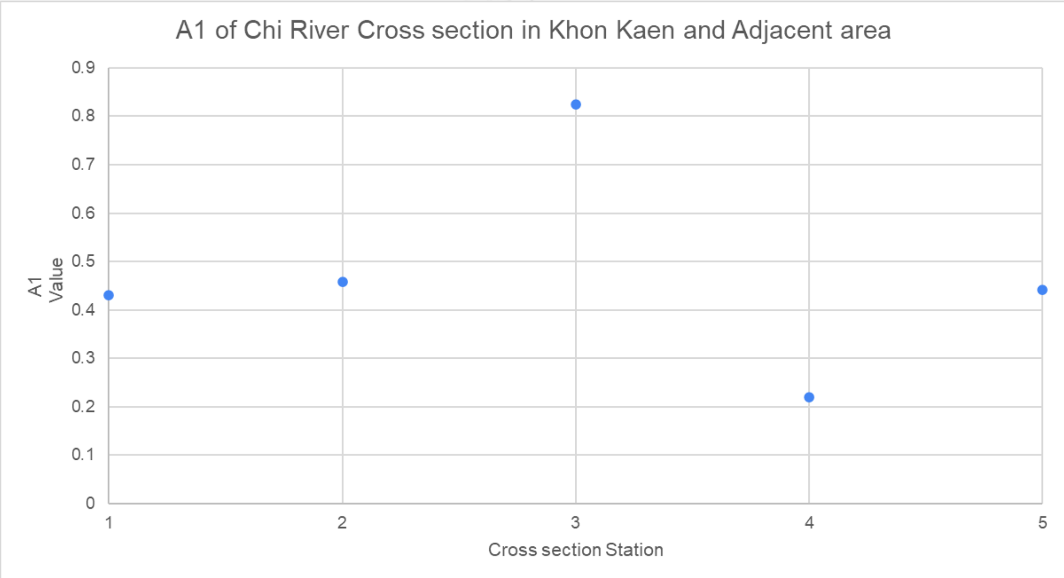

Figure 67 The graph of A1 of Chi river cross-section in Chi river in Muang Khon Kaen district and adjacent areas.

Figure 67 shows the graph of A1 value. X-axis is the station that was collected cross-sectional shape of the channel, and Y is A1 value. According to the graph, station 3 is the most asymmetry channel that has A1 value of 0.82. The second asymmetry channel is station 2 that has A1 value of 0.45. The third asymmetry channel is station 5 that has an A1 value of 0.44. The fourth asymmetry channel is station 1, with an A1 value of 0.42, while station 1 is considered the most symmetry channel with an A1 value of 0.22.

4.6.2.3 A2

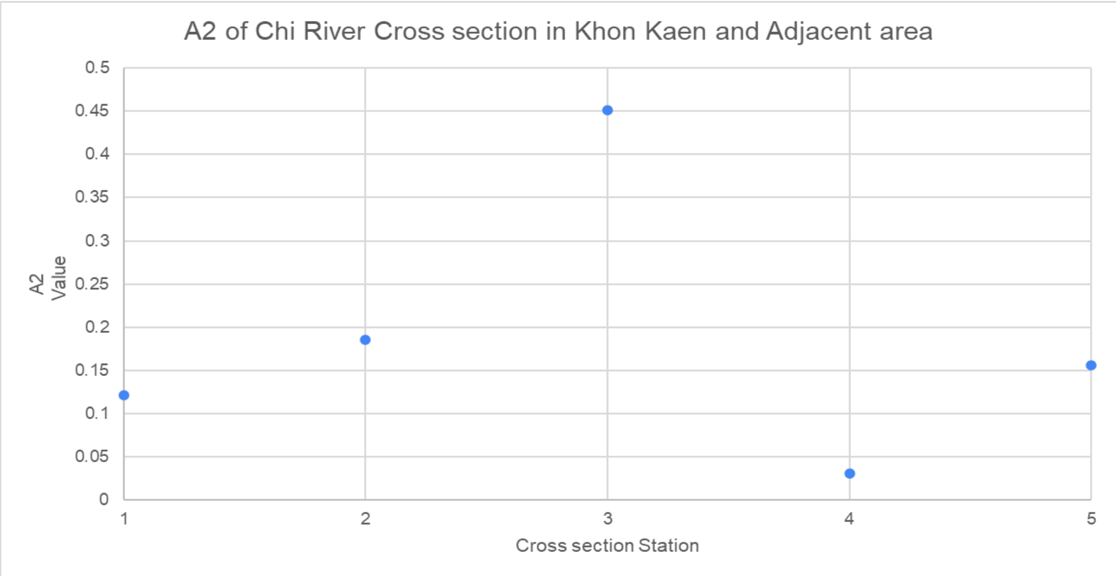

Figure 68 The graph of A2 of Chi river cross-section in Chi river in Muang Khon Kaen district and adjacent areas.

Figure 68 shows the graph of A2 value. X-axis is the station that was collected cross-sectional shape of the channel, and Y is A2 value. According to the graph, station 3 is the most asymmetry channel that has A2 value of 0.45. The second asymmetry channel is station 2 that has A2 value of 0.18. The third and fourth asymmetry channels are station 4 and station 1, with A2 values as 0.15 and 0.12, respectively. While station 1 is considered as the most symmetry channel that has A2 value of 0.03.

4.6.3 Asymmetry index from Das and Islam (2018)

4.6.3.1 A_w

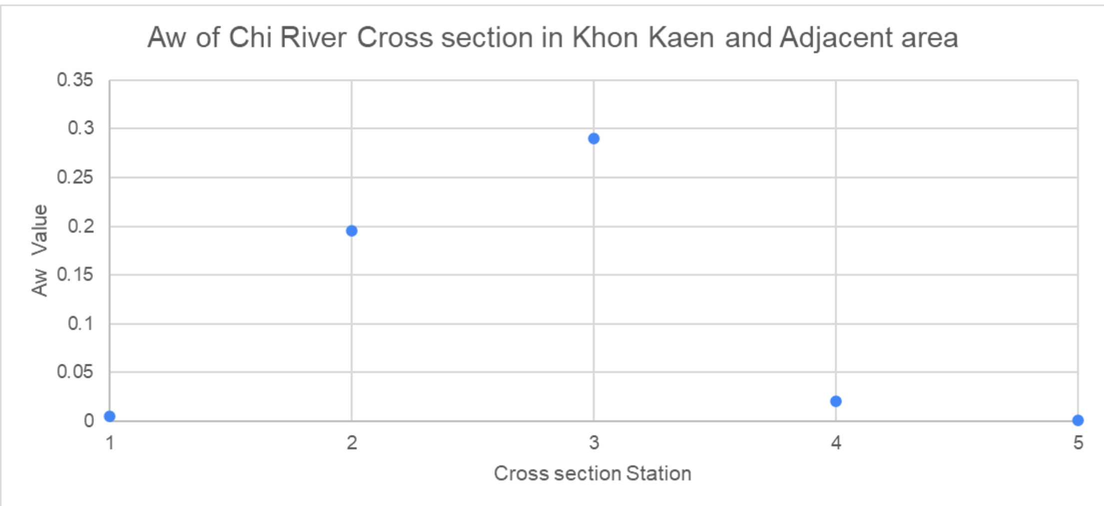

Figure 69 The graph of A_w of Chi river cross-section in Chi river in Muang Khon Kaen district and adjacent areas.

Figure 69 shows the graph of Aw value. X-axis is the station that was collected cross-sectional shape of channel and Y is Aw value. According to the graph, station 3 is considered the most asymmetry channel because it has the highest Aw value of 0.30. The second asymmetry channel is station 2 that has Aw value of 0.2. The third asymmetry of the channel is station 4 that has Aw value of 0.025. While station 1 and station 5 are considered symmetry channels because their value is close to 0.

4.6.3.2 A_a

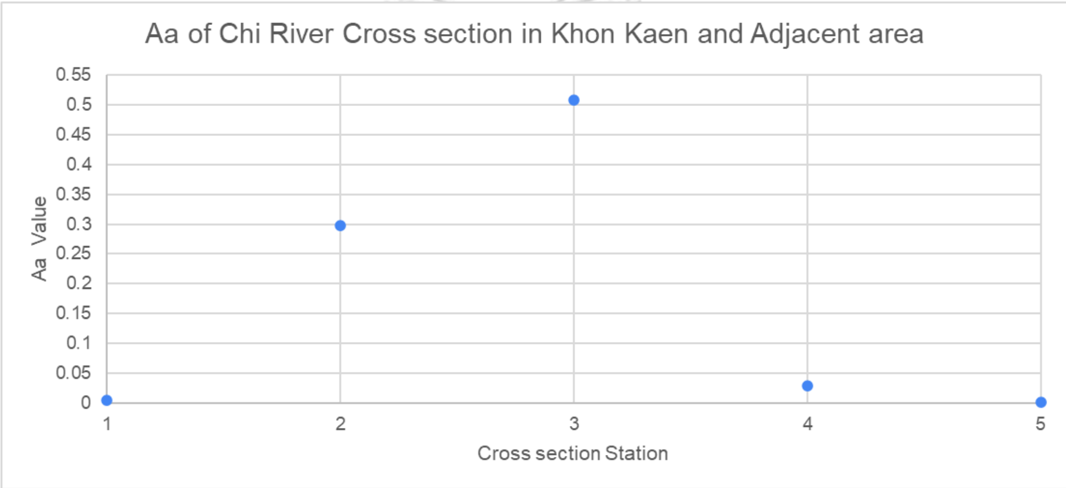

Figure 70 The graph of A_a of Chi river cross-section in Chi river in Muang Khon Kaen district and adjacent areas.

Figure 70 shows the graph of Aa value. X-axis is the station that was collected cross-sectional shape of channel Y-axis is Aa value. According to the graph, station 3 is considered the most asymmetry channel because it has the highest Aa value as 0.508. The second asymmetry channel is station 2 that has Aw value of 0.297. The third asymmetry of the channel is station 4 that has Aa value of 0.025. The rest station is considered a symmetry channel because its value is close to 0.

4.6.3.2 A_{wa}

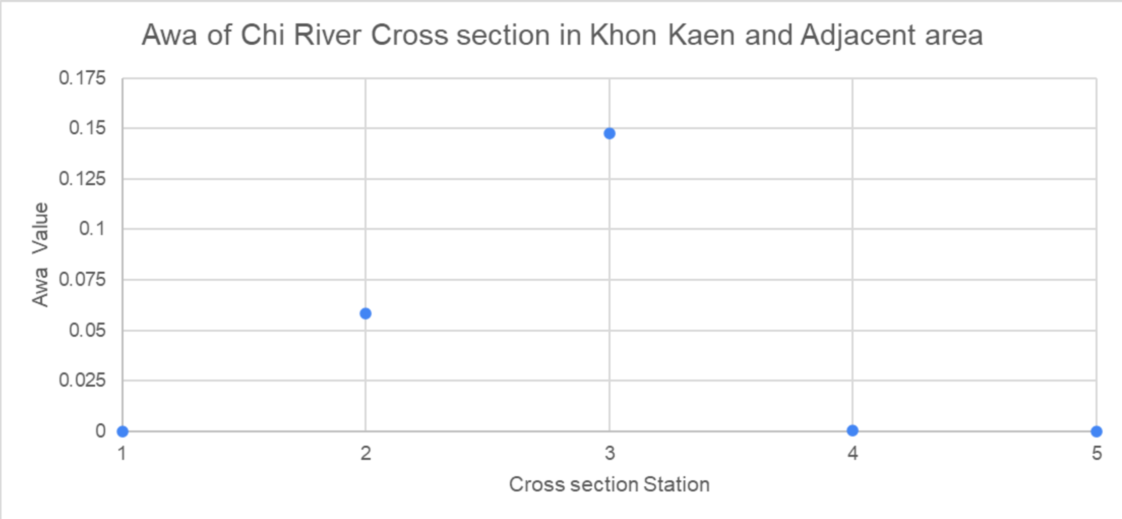

Figure 71 The graph of A_{wa} of Chi river cross-section in Chi river in Muang Khon Kaen district and adjacent areas.

Figure 71 shows the graph of Awa value. X-axis is the station that was collected cross-sectional shape of channel, and Y is Awa value. According to the graph, station 3 is considered the most asymmetry channel because it has the highest Awa value as 0.147. The second asymmetry channel is station 2 that has Awa value of 0.05. The rest station is considered a symmetry channel because its value is close to 0.

Chapter 5: Discussion

This chapter provides the discussions of all results from remote sensing analyses and field surveys leading to the assessment of the Chi river's hydromorphological changes in Khon Kaen. Discussion consists of four parts: changing of flood boundary, the asymmetry of the channel, the geomorphic index changes area, and the relationship between geomorphic index changes and MQI score.

5.1 Changing of flood boundary

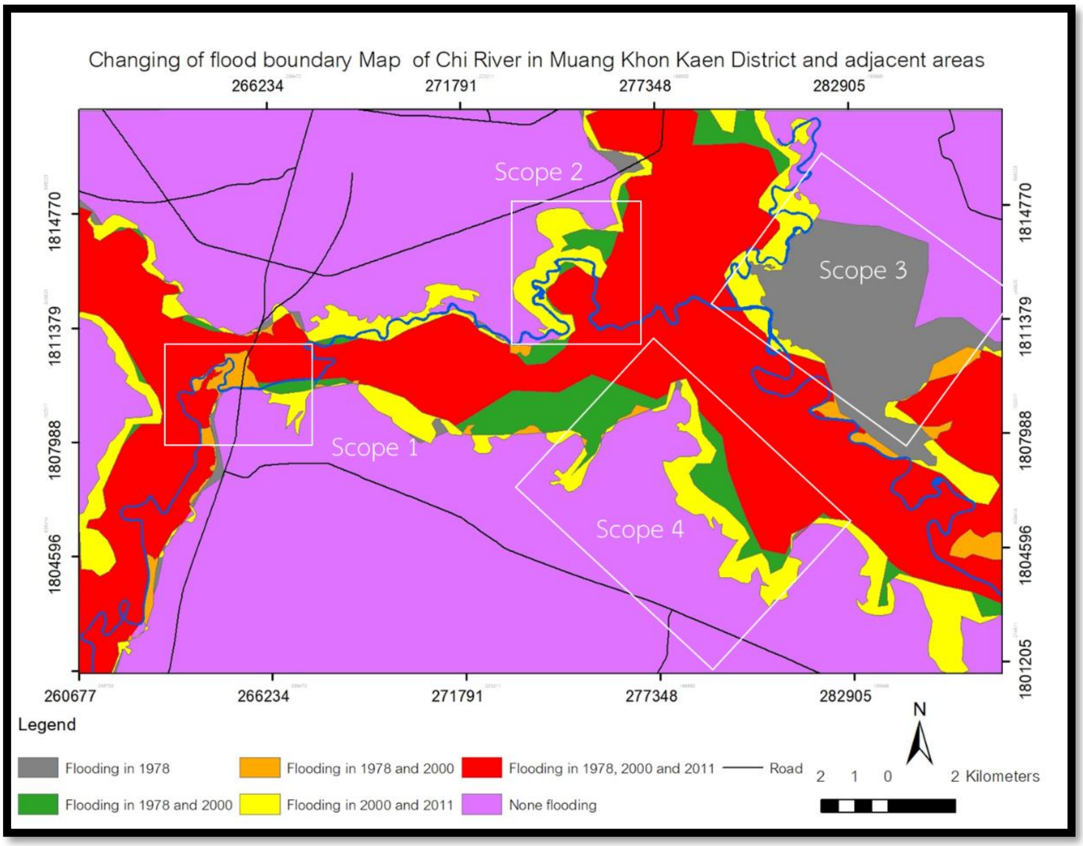

Figure 72 The changing of flood boundary of Muang Khon Kaen district and adjacent areas.

Figure 72 shows the map of changing of flood boundary. It has 4 scopes that has interested changing of flood boundary.

5.1.1 Scope 1

Figure 72 shows the changing of flood boundary in scope 1. This scope consists of 4 areas: Flooding in 2000 and 2011 area covering 220,751.42 square meters, flooding in 2011 area covering 251,344 square meters, flooding in 1978 and 2000 area covering 1,231,760 square meters and lake covering 423,558.98 square meters. Thus, the area of flooding in this scope decreased about 759,664.56 square meters. The field survey revealed that this scope has an artificial lake (Figure 74) that was modified from an abandoned channel. Therefore, it can be summarized that making an artificial lake is one way for flood mitigation. Moreover, this lake can be used for water management in the dry season.

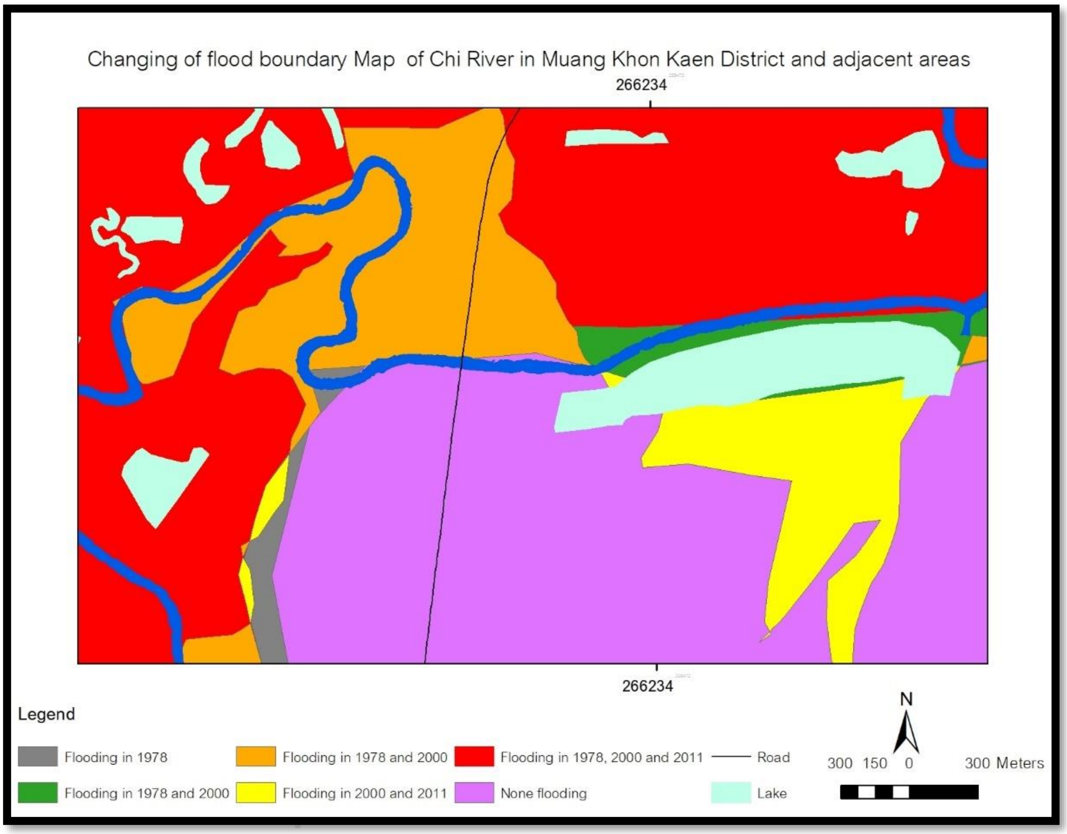

Figure 73 The changing of flood boundary of Scope 1.

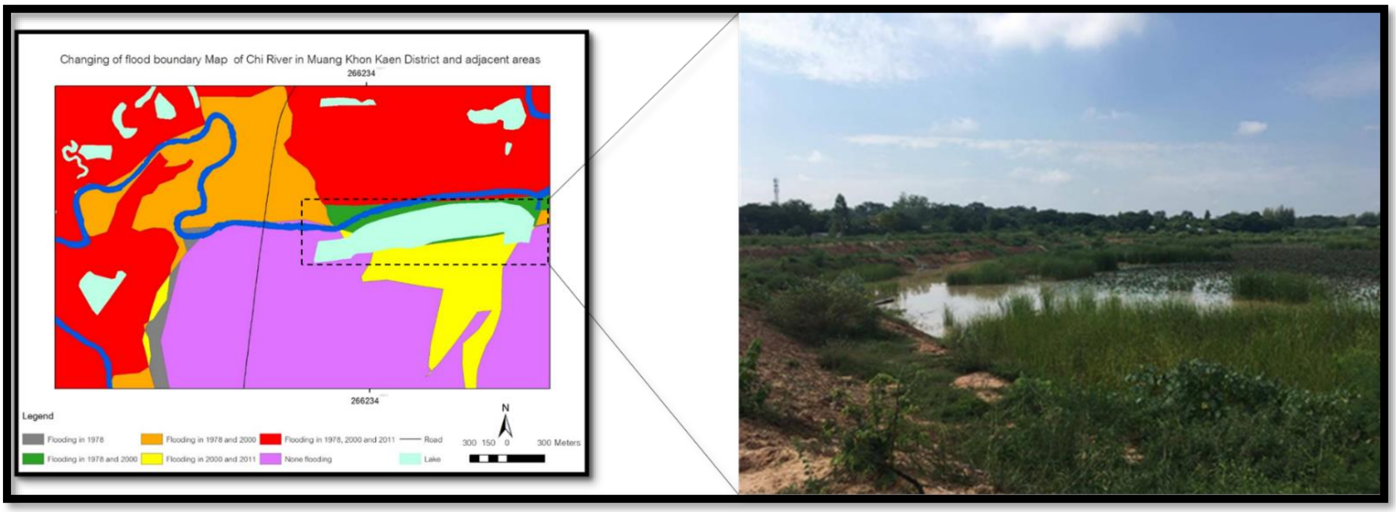

Figure 74 The artificial lake in Scope 1.

5.1.2 Scope 2

Figure 75 shows the changing of flood boundary in scope 2. This scope consists of 2 Areas: Flooding in 2000 and 2011 area and Flooding in 2011 area. However, this scope has a road that has constructed after 1978. Thus, the extension of the flood boundary of this area will be caused by the meander belt extension.

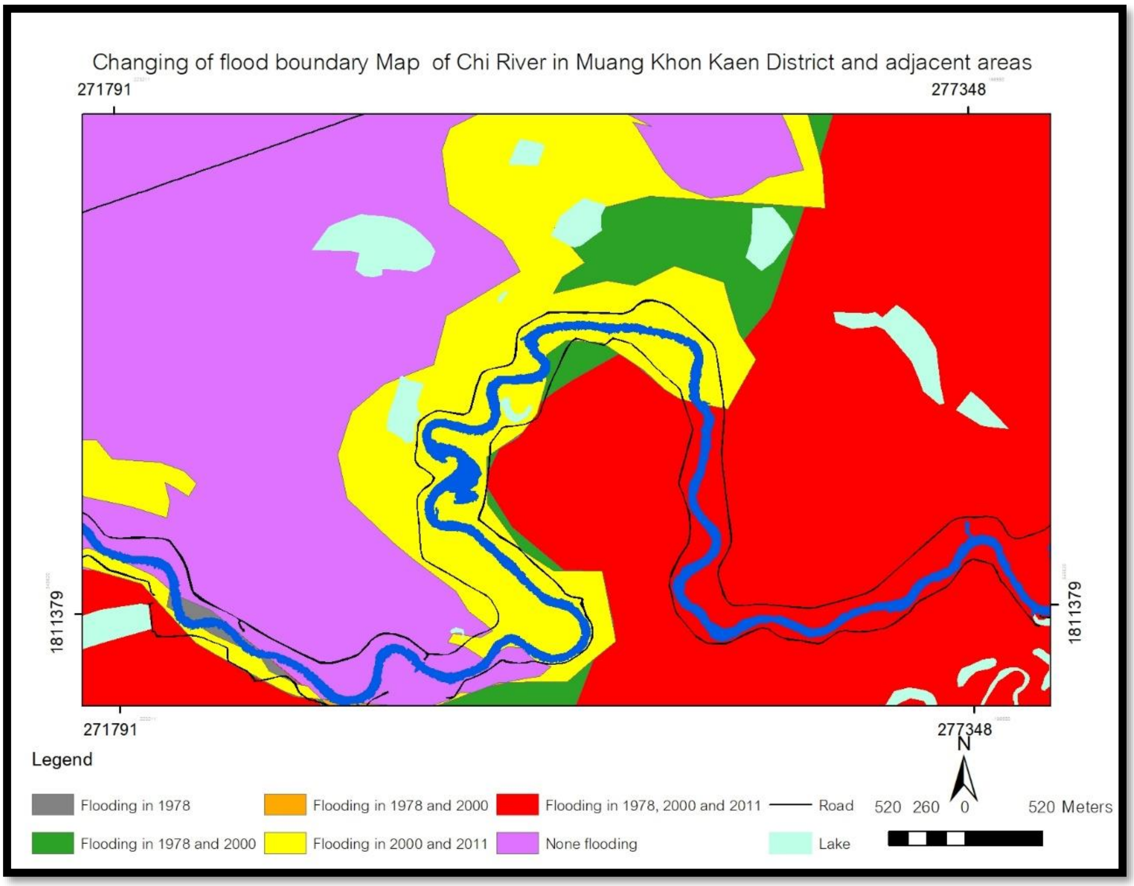

Figure 75 The changing of flood boundary of Scope 2.

5.1.3 Scope 3

Figure 76 shows the changing of flood boundary in scope 3. This scope consists of 2 areas: flooding in 2000 and 2011 area and flooding in 2011 area. Thus, the flooded area in this scope has increased since 2000. According to the field survey, it found that this area has a drainage system that is displayed in Figure 77. The drainage system alters the direction of overflow. Thus, the extension of the flood boundary may be caused by the drainage system.

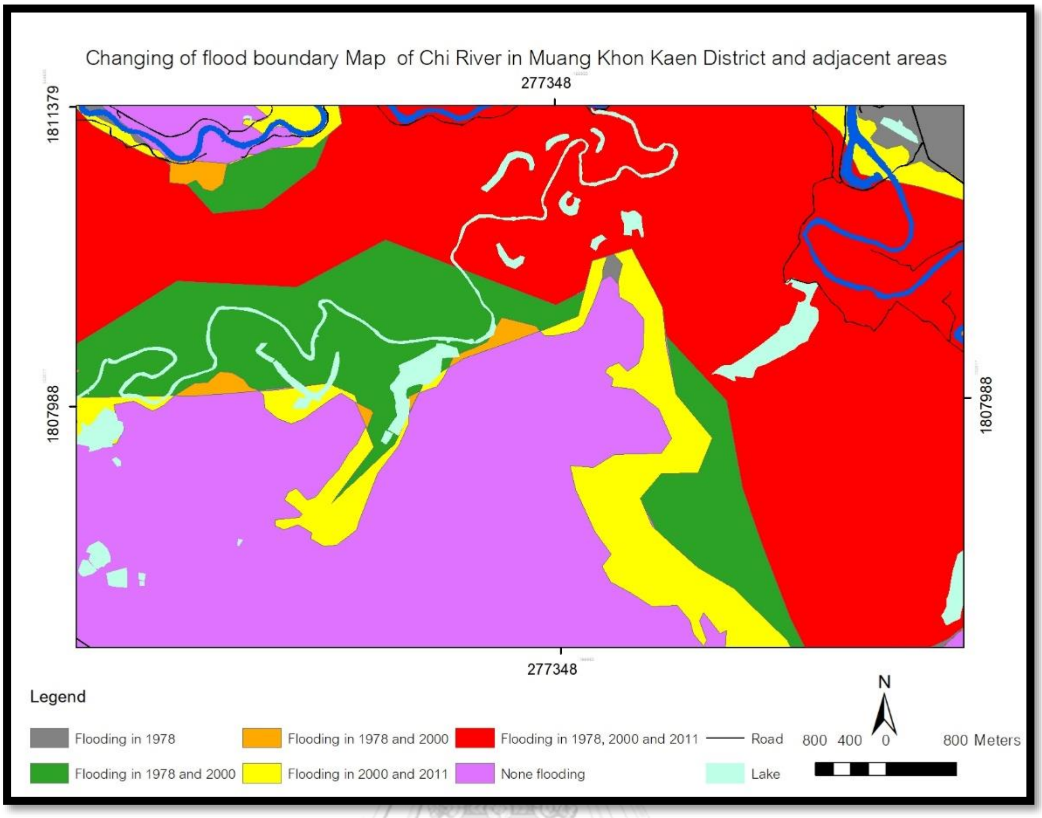

Figure 76 The changing of flood boundary of Scope 3.

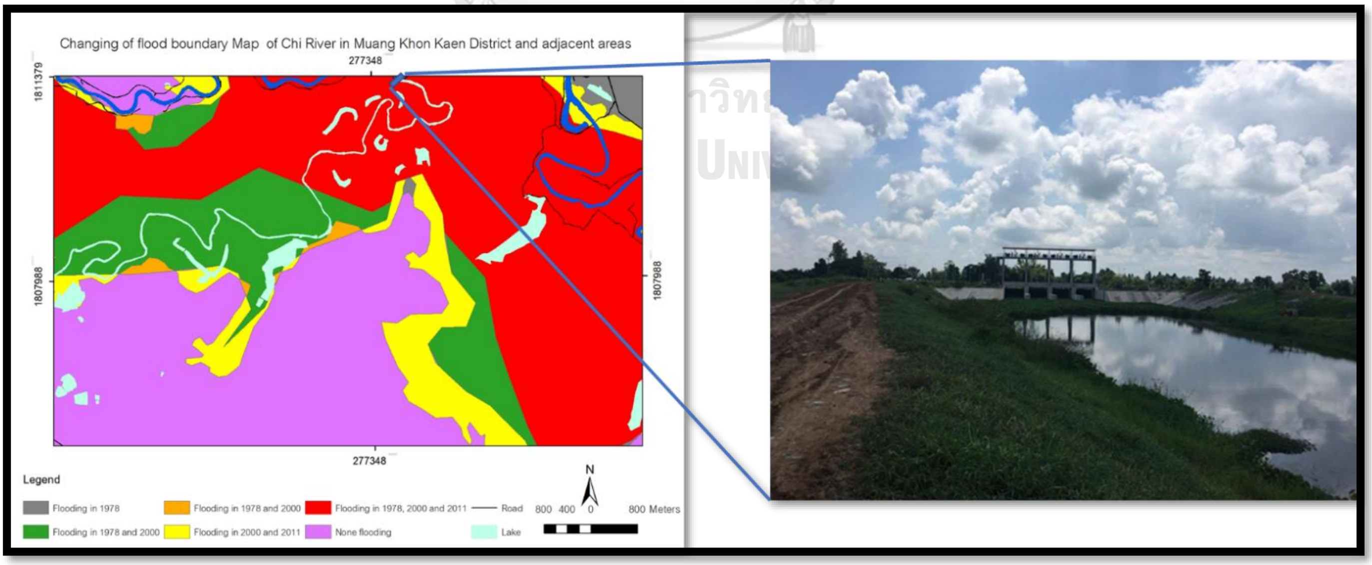

Figure 77 The drainage system in Scope 3.

5.1.4 Scope 4

Figure 78 shows the changing of flood boundary in scope 4. This scope consists large area of flooding in 1978 area . This area has the main road that was constructed after 1978. This road may be blocked the overflow. Thus, the flood area may be decreased from this road about 31,067,500 square meters.

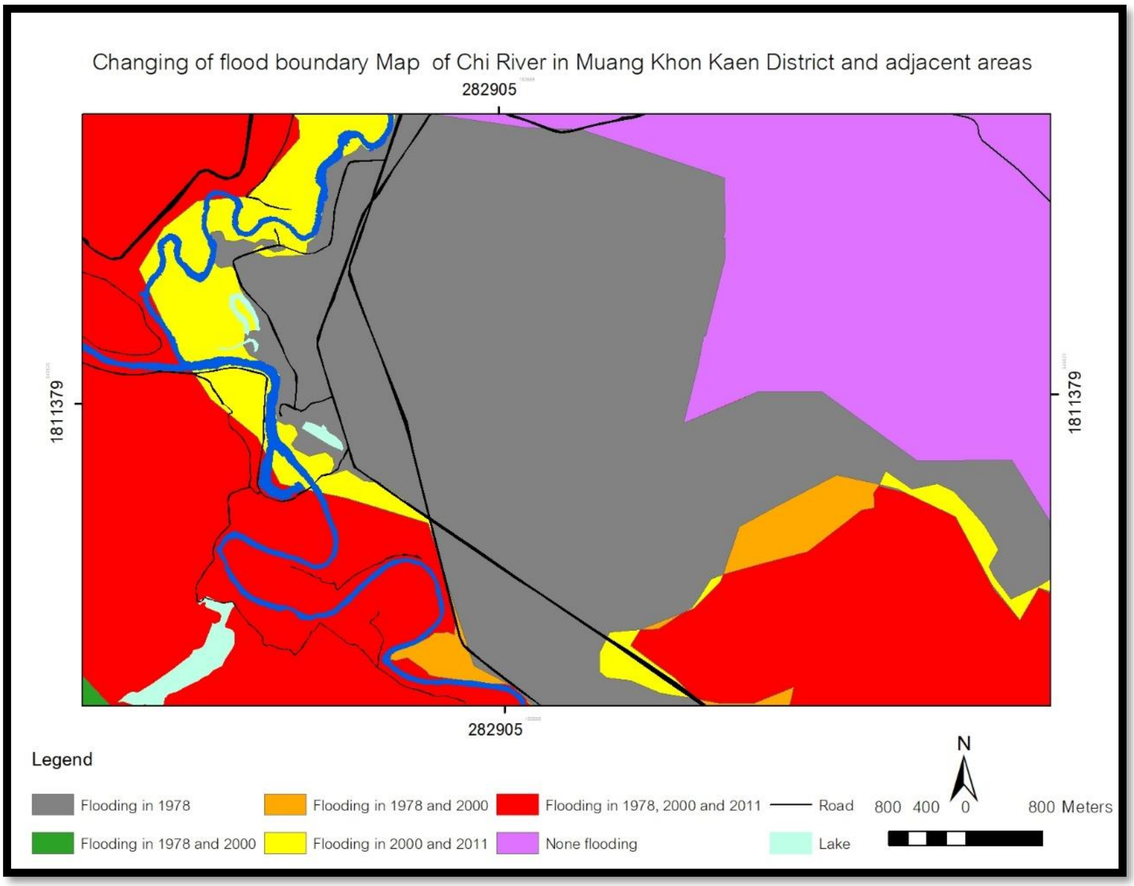

Figure 78 The changing of flood boundary of Scope 4.

5.2 The asymmetry of channel

The asymmetry of a channel is calculated from cross-sectional data with six asymmetry index that was collected in October 2020. Station 3, the upstream station that nears the irrigation dam has the most degree of asymmetry channel because this station has the most extreme value of all asymmetry indices. Station 2 that doesn't near the irrigation dam is the second most asymmetry channel. The most symmetry channel is station 1 and 5 because their value of almost asymmetry indices is strongly near to 0. However, their value of A1 and A2 is higher than station 4.

Because station 1 and 5 the distance between max depth line and the centerline of station 1 and station 5 are more than station 4.

According to the previous study, human intervention is the essential factor influencing the level of asymmetry of the channel (P. Das, Let, & Pal, 2013).But this study found that not only intervention but also location is the essential factor that affects the level of asymmetry. It can be seen that from station 4 that has the highest percentage of artificiality (about 45 %) doesn't have the most degree of channel asymmetry. However, station 3 that locates in upstream area and doesn’t has the most percentage of artificiality (about 25 %) is the most asymmetry channel. Thus, it will be assumed that the station's location: upstream or downstream, is one of the most critical factors that impacts to the level of asymmetry channel. Also, station 2 has a percentage of artificiality only 30 % but has the second most asymmetry degree. In comparison, station 5 has a percentage of artificiality about 35 %, but this station is the most symmetry of channel.

5.3 The geomorphic index changes of the upstream area and downstream

This part discusses the geomorphic index changes of the upstream area and downstream area of an irrigation dam in three topics: migration rate, widening rate and depositional and erosional area of downstream.

5.3.1 Migration rate

Figure 79 shows the graph of the average migration rate of channel width in the upstream area and downstream area of an irrigation dam in four different periods: 1952 to 1988, 1988 to 1992, 1992 to 2006, and 2006 to 2020. According to the graph, the X-axis is the period, and the Y-axis is migration rate that was measured in meters per year. Overall, the average migration rate after the construction of the irrigation dam (1988) of the downstream area was higher than the upstream area. For the upstream area, the average migration rate increased from 0.463 meters per year in period 1952 to 1988 to 0.726 meters per year in period 1992 to 2006. Then, it decreased to 0.539 meters per year in the period 2006 to 2020. For downstream areas, the average migration rate dramatically increased from just 0.468 meters per year in period 1952 to 1988 to 2.26 meters per year in the period 1988 to 1992. The migration rate in downstream area dramatically increased because migration rate at dam construction in period 1988 to 1992 was 92 meters per year (Station 467). Then, it decreased to 0.726 meters per year in period 1992 to 2006. Finally, it increased to 0.908 meters per year in the period 2006 to 2020.

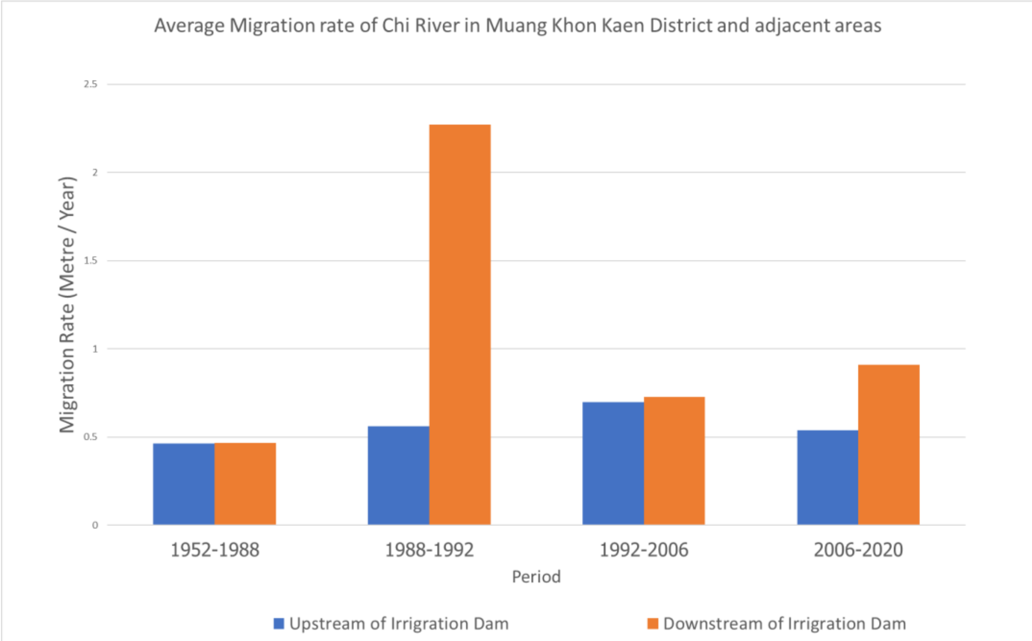

Figure 79 The graph of average migration rate in the upstream area and downstream area of an irrigation dam.

The migration rate in the study area is correspond to the previous study that the dam construction has an effect on geomorphological downstream (Lai et al., 2017; D. Li et al., 2019; Makaske et al., 2012; Petts & Gurnell, 2005; Phillips, 2009; Williams & Wolman, 1984). It can be seen from the downstream's migration rate dramatically increased in period 1988 to 1992 (Construction period) while up stream's migration rate didn't significantly alter.

5.3.1 Widening rate

Figure 80 shows the graph of the average widening rate in the upstream area and downstream area of an irrigation dam in four different periods: 1952 to 1988, 1988 to 1992, 1992 to 2006, and 2006 to 2020. According to the graph, the X-axis is the period, and the Y-axis is widening rate that was measured in meters per year. For the upstream area, the average widening rate decreased from 0.311 meters per year in period 1952 to 1988 to -0.02 meters per year in period 1988 to 1992. Then, it increased to 0.711 meters per year in period 1992 to 2006.Finally, it decreased to -0.18 meters per year in period 2006 to 2020. For the downstream area, the widening rate decreased from 0.31 meters per year in period 1952 to 1988 to -0.06 meters per year in period 1988 to 1992. Then, it rose up to 0.179 meter per year in the period 1992 to 2006. Finally, it decreased -0.90 meter per year in period 2006 to 2020. The widening rate of downstream area has decreased after the dam operated that different with previous study (Wang et al., 2018).

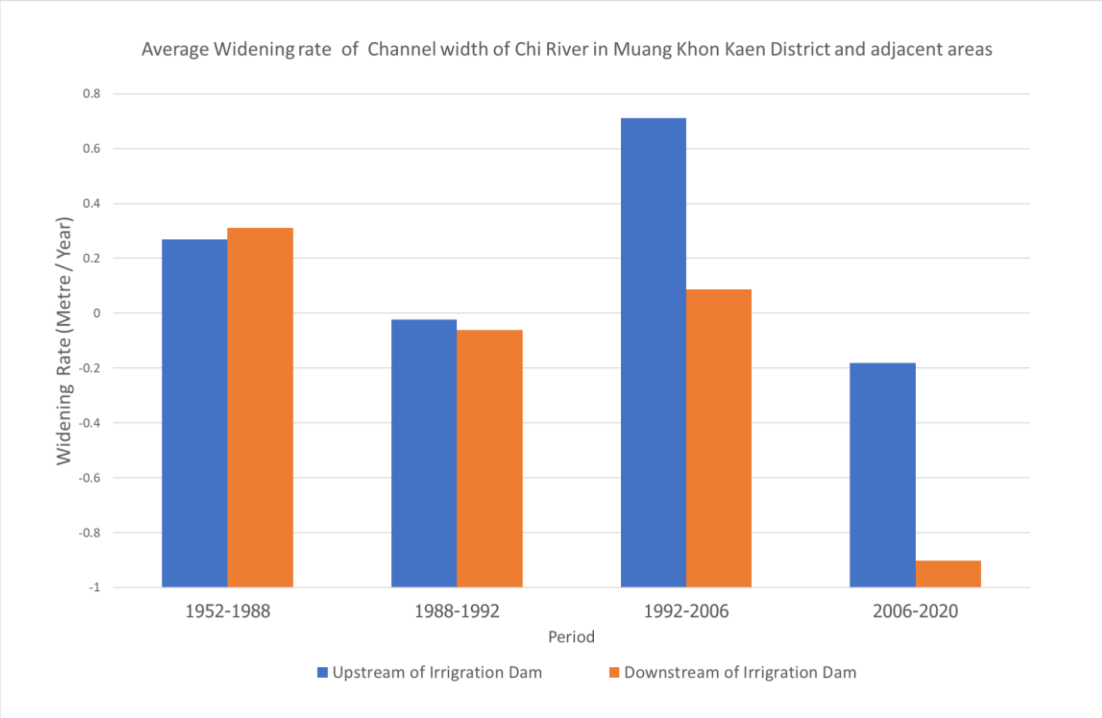

Figure 80 The graph of average widening rate in the upstream area and downstream area of an irrigation dam.

The average widening rate of downstream area in period 2006 to 2020 is less than 0. It isn't corresponded with Wang et al. (2018) that the channel width has increased after the dam operated. Figure 81 shows the widening rate of downstream irrigation dam area in the period 2006 to 2020. According to the graph, the X-axis is the station, and the Y-axis is widening rate that was measured in meters per year. It can be seen that almost stations of downstream area (from station 647 to last station) has widening rate less than 0 in this period except the sand mining area (station 602) that has widening rate more than 0 in this period.

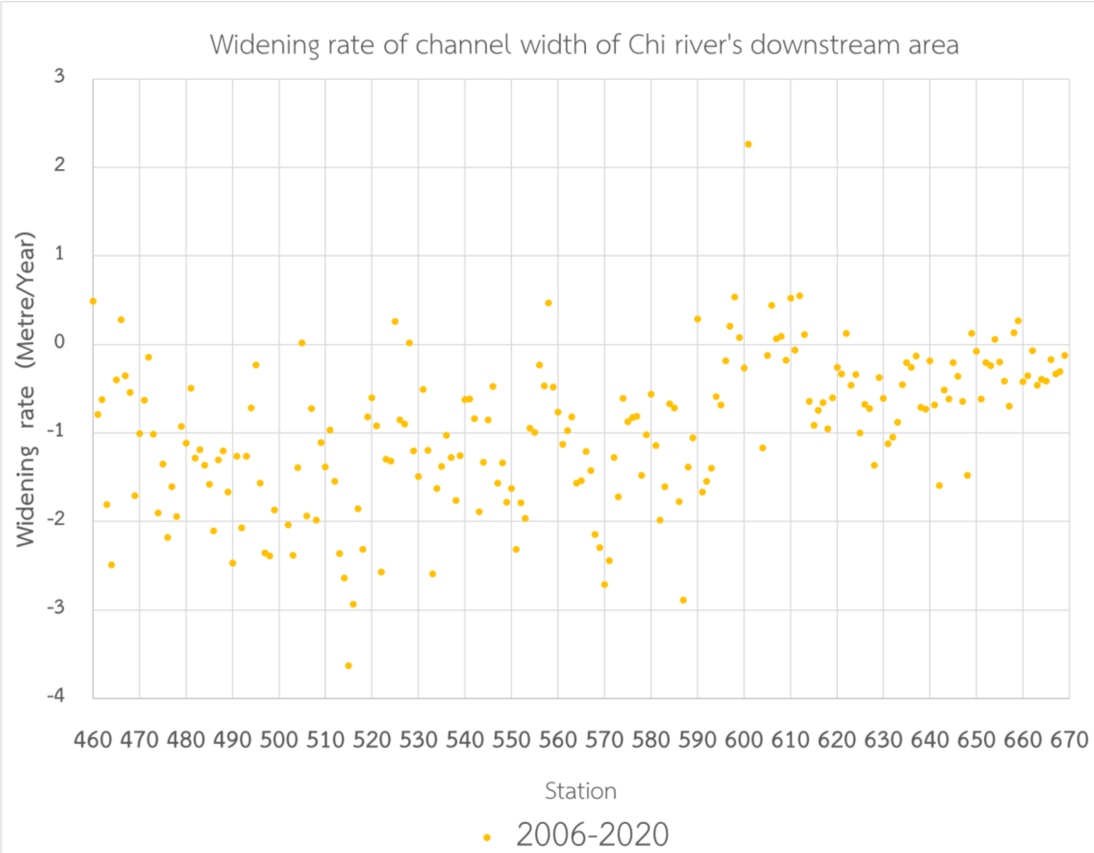

Figure 81 The graph of widening rate in downstream area of an irrigation dam.

5.3.3 Depositional area and erosional area of downstream of irrigation dam area

According to Figure 80, the widening rate of downstream area in period 2006 to 2020 is less than 0, which doesn't correspond with the previous study that the width of the channel in the downstream area has increased after the dam operated. It implies that this area doesn't have bank erosion process. Because bank erosion process increases channel width (Wang et al., 2018). Thus, investigation of depositional and erosional processes in the downstream area may be described the widening rate of downstream area in period 2006 to 2020.

Figure 82 that shows the depositional and erosional area of downstream area in period 2006 to 2020.According to Figure 80, red color area presents the erosional area and green color area presents the depositional area. It can be seen that the depositional areas in downstream area have more than erosional areas. Thus, it can conclude that these depositional areas caused a narrow channel.

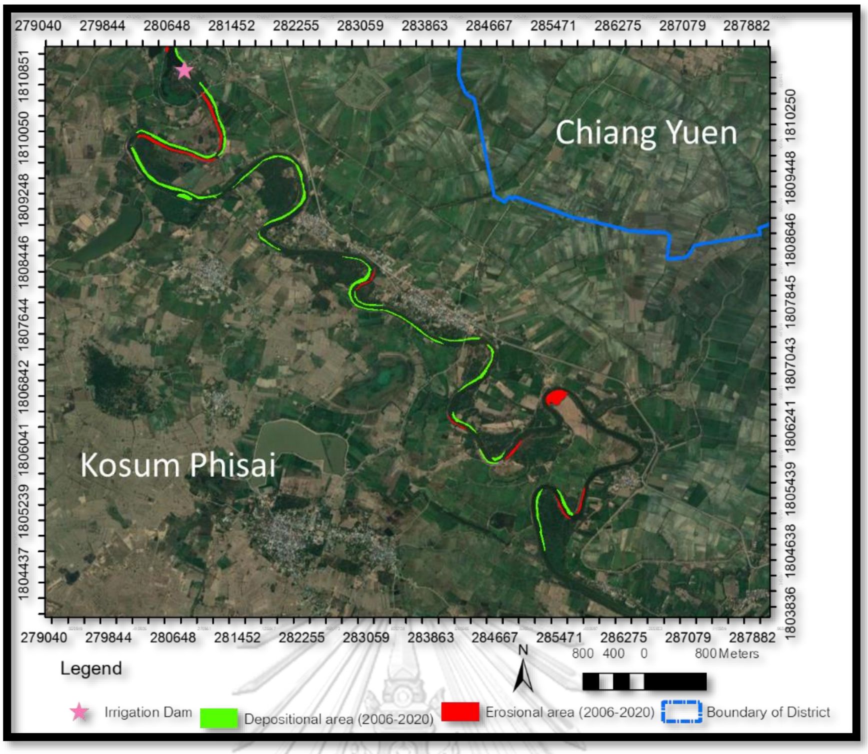

Figure 82 The map of the depositional and erosional areas in downstream area of an irrigation dam.

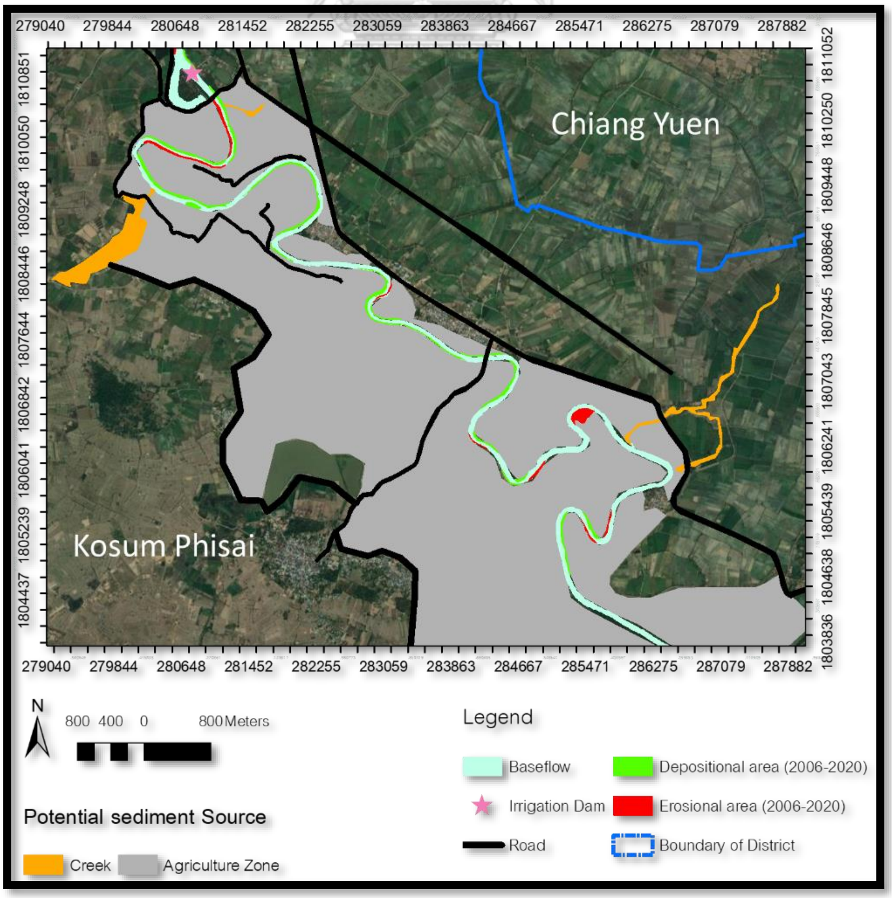

Figure 83 The map of potential source of sediment in downstream area of an irrigation dam.

It is different from previous studies that the downstream damming's sediment supply dramatically decreases (Dai & Liu, 2013; Lai et al., 2017; Lyu et al., 2019). However, it can describe in Figure 83 shows the potential sources of sediment in the downstream area. This study area has four creeks that connects to main river and the floodplain that nears river is an agriculture zone that has the activities such as plowing the surface. In addition, this floodplain often suffers from flooding that may be carried the sediment from surface of floodplain to the main river. Thus, it may imply that the sediment of the Chi river in downstream area may be come from creek that connects to river and agriculture zone.

5.4 The relationship between MQI Score and geomorphic index changes

This part discusses the relationship between MQI and geomorphic index changes that include sinuosity index, widening rate and migration rate. Table 5 shows reach scale that has significant geomorphic index changes.

Reach	Sinuosity Index	Widening rate	Migration rate	Morphological Quality: Moderate Class
2	X	-	-	-
5	X	-	-	-
10	X	-	-	X
11	-	-	-	X
16	-	X	X	-
20	X	-	-	-
21	-	-	-	X
24	-	X	X	X

Table 5 Significant reach scale

5.4.1 Reach 2

Figure 84 shows the sinuosity index value of scope A in 5 different periods: 1952, 1988, 1992, 2006, and 2020. According to the graph, Y-axis is the Sinuosity index value, and X-axis is a year. The sinuosity index increased from 4.12 in 1952 to 4.55 in 2006. Then, it reduced to 4.52 in 2020. Thus, the sinuosity index increased 0.43 from 1952. According to the MQI score of this reach, it doesn't indicate that this reach has a high level of distribution from the artificial element. Thus, it may be concluded that the alteration of sinuosity index in this reach is caused by only natural processing.

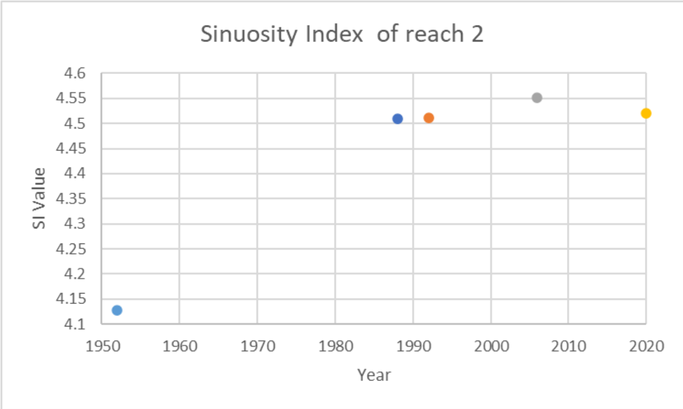

Figure 84 The graph of Sinuosity index of Chi River in reach 2.

Figure 85 shows the boundary of the channel in reach 2 in three different periods: 1952, 1992 and 2020. It can be seen that the channel width in black scope has extended that affects to channel planform in white scope. It altered from straight river to sinuous river. Thus, the Sinuosity index of reach 2 increased.

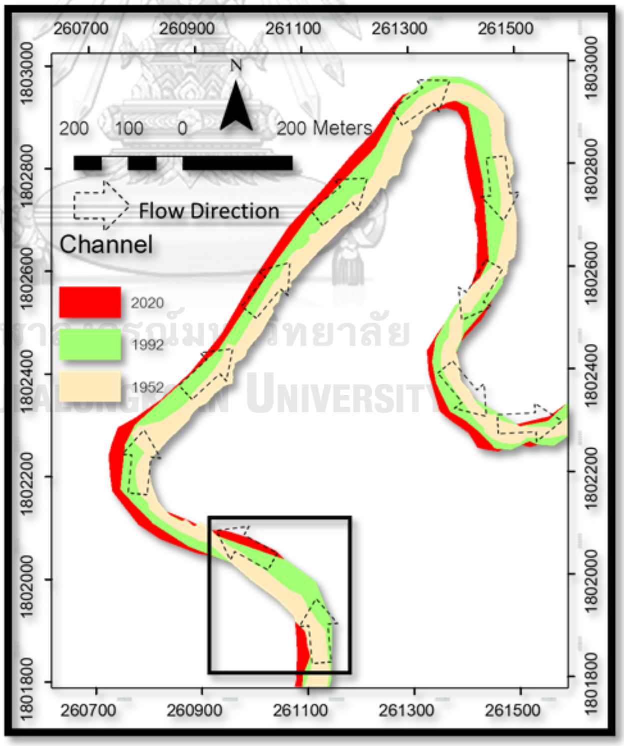

Figure 85 boundary of the channel in reach 2 in 1952, 1992 and 2020.

5.4.2 Reach 5

Figure 86 shows the sinuosity index value of reach 5 in 5 different periods: 1952, 1988, 1992, 2006, and 2020. According to the graph, Y-axis is the Sinuosity index value, and X-axis is a year. The sinuosity index decreased from 3.71 in 1952 to 3.32 in 1992. Then, it increased to 3.37 in 2020. According to the MQI score of this reach, it doesn't indicate that this reach has a high level of distribution from artificial elements. Thus, it may be concluded that the alteration of sinuosity index in this reach is caused by only natural processing.

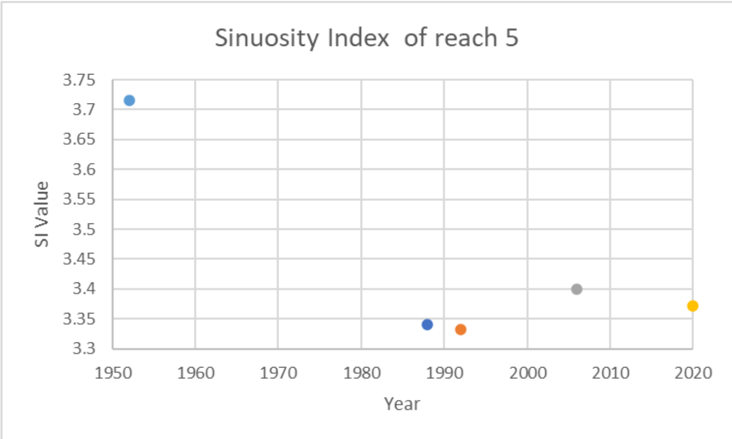

Figure 86 The graph of Sinuosity index of Chi river in reach 5.

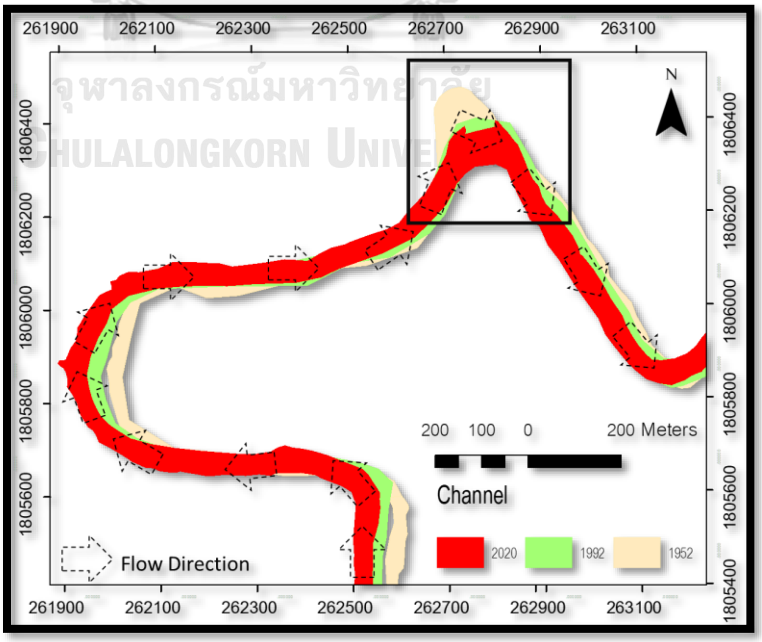

Figure 87 The boundary of the channel in reach 5 in 1952, 1992 and 2020.

Figure 87 shows the boundary of the channel reach 5 in two different periods: 1952, 1992 and 2020. It can be seen that in white scope has chute cut off process during 1952 to 1992. This process reduced overall of sinuosity index value of reach 5.

5.4.3 Reach 10 and Reach 11

The sinuosity index of reach 10 dramatically increased from 2.46 in 1952 to 2.87 in 1992. Then, it reduced to 2.84 in 2020. According to the MQI of this reach, it indicates that this reach has a high level of distribution from artificial elements because the percentage of artificiality is high. In this reach has artificial elements that affects to hydro morphology: bridge that affects to river continuity, bank protection that affects to river width and depth. Moreover, modification oxbow lake in this reach affects to floodplain. However, it may be assumed that the alteration of sinuosity index in this reach is caused by only natural processing because the percentage of artificiality is high from many constructions of developed housing that were constructed after 2000. But the sinuosity index value dramatically increased in the period 1952 to 1992.

According to reach 11, the MQI score is lower than other reaches because this reach has artificial elements and activates that affects to hydrogeomorphology such as many bridges in this reach affects to Longitudinal River continuity, modification river affects to river width and depth and modification abandoned channel affects to floodplain.

5.4.4 Reach 16

Although the MQI score of reach 16 doesn’t indicate that this reach has a high level of disturbance from artificial elements and hydromorphological alteration, it has two stations that have a significant migration rate and widening rate: station 345 and station 392.Figure 88 shows the location of two stations.

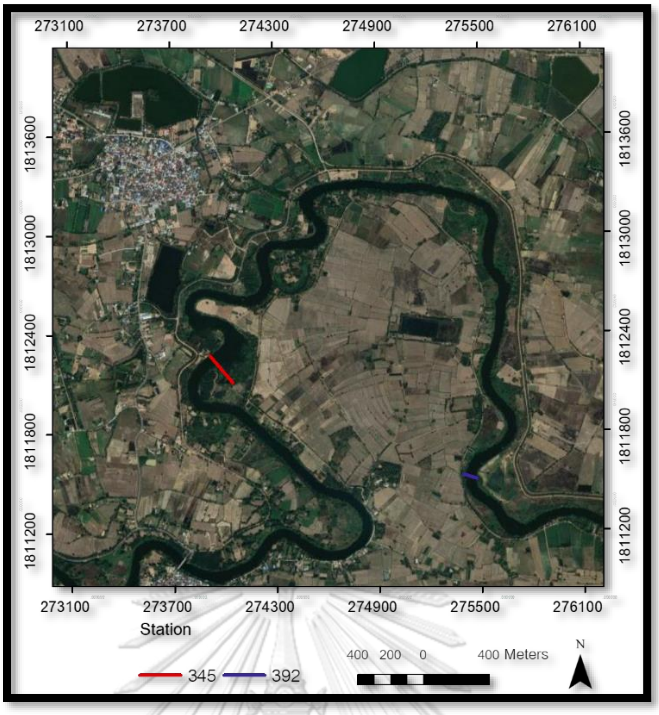

Figure 88 The location of station 345 and 392.

First, station 345 has a widening rate of 9.66 meters per year in the period 1992 to 2006 and a migration rate of 4.65 and 4.12 meters per tear in the period 1992 to 2006 and 2006 to 2020, respectively. According to the depositional area and erosional area map (Figure 89), it can be seen that the erosional area of this station has increased. Figure 90 shows the erosional area of station 345 that was taken from a field survey in October 2020.

Figure 89 The depositional and erosional map of station 345.

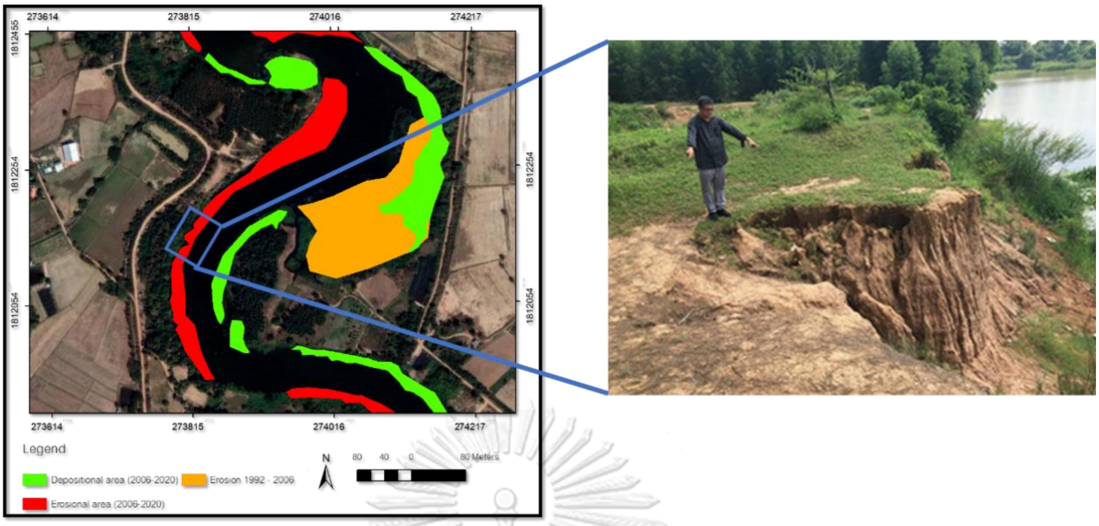

Figure 90 The erosional area of station 345 that was taken from a field survey in October 2020.

Second, station 392 has a widening rate of 3.88 meters per year in the period 1992 to 2006 and a migration rate of 2.62 meters per year in the period 1992 to 2006. Figure 91 shows the depositional area and erosional area map of station 392 in the period 1992 to 2006. It can be seen that it has a large erosional area that was eroded in period 1992 to 2006.

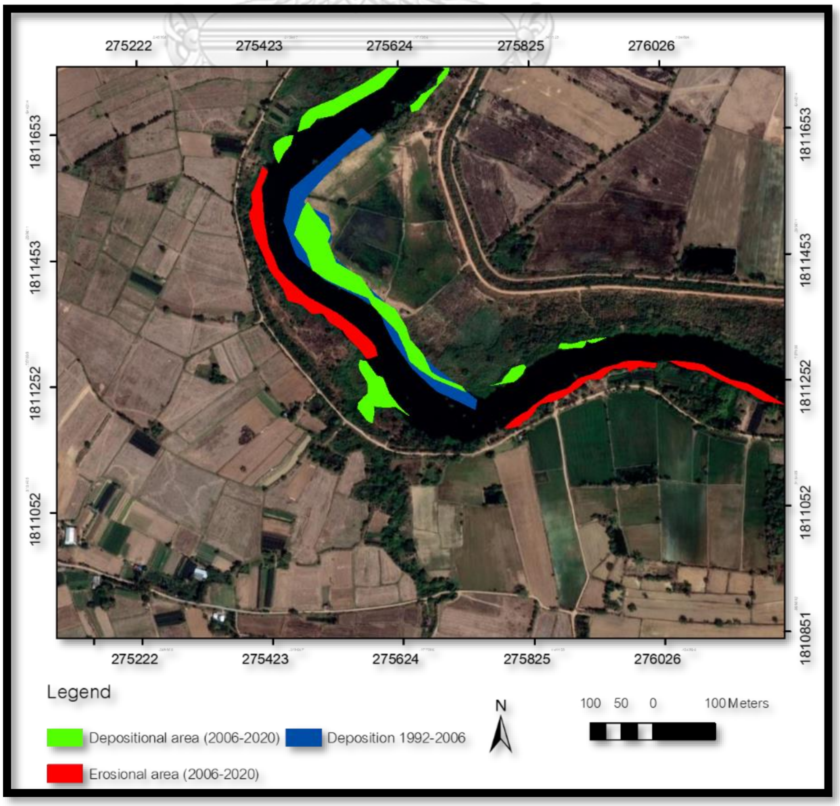

Figure 91 The depositional and erosional map of station 392.

According to the MQI Score, it doesn't indicate that this reach has a high level of disturbance from artificial elements. Thus, it may be concluded that the widening of the channel is natural processing.

5.4.5 Reach 20 and Reach 21

The channel planform of reached 20 has altered from meandering river to sinuous river that was measured by sinuosity index. The sinuosity index value of this reach dramatically decreased from 1.5368 in 1988 to just 1.34 in 1992.

For reach 21, the MQI score indicates this reach has a high level of disturbance from artificial elements. Moreover, stations 467 and 468 have a migration rate more than 70 meters per year in the period 1988 to 1992. The alteration in reach 20 and 21 caused by the irrigation dam. The irrigation dam changed the flow direction of the Chi River. Figure 92 shows the flow direction of the downstream area that nears the irrigation dam in two different periods: before and after the construction of the dam. It can be seen that the channel has migrated to the west from the previous flow direction. Thus, the migration rate during construction is anomaly higher than other stations and other periods. Moreover, this dam impact on hydromorphology in many topics: Quality and dynamic water flows, River Continuity, River width and depth and floodplain.

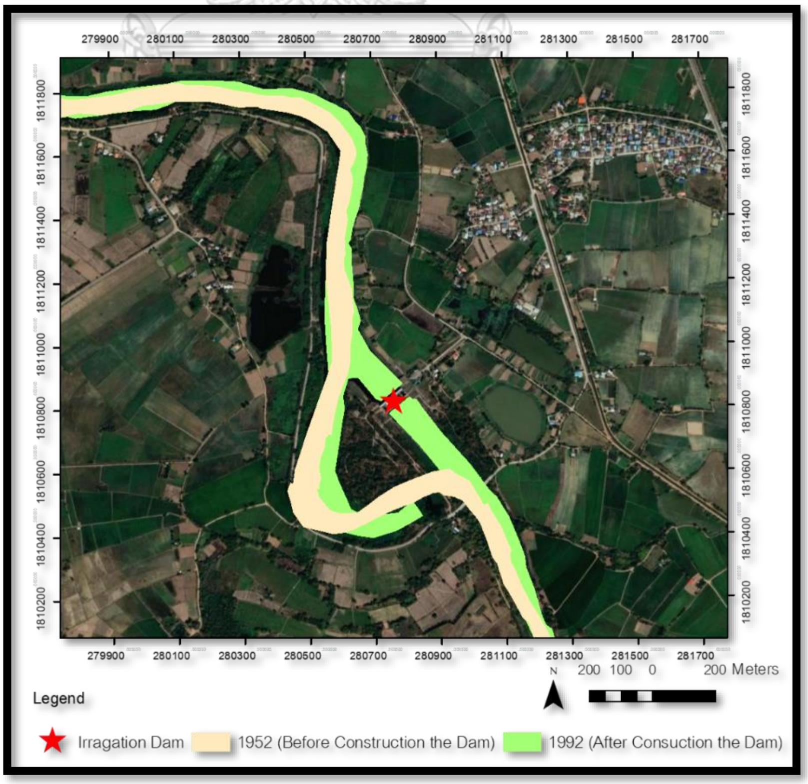

Figure 92 The flow direction of the downstream area that nears the irrigation dam in two different.

5.4.6 Reach 24

MQI score of reach 24 indicates that this reach has a high level of disturbance from artificial elements. According to the field survey in October, it was found that this reach has bank protection (Figure 93) and Sand mining in the Chi River. For discussion, this reach has 3 sections that have significant alteration: Section A, Section B, and Section C. Figure 94 shows the locations of these scopes in two different periods: 1952 and 2020.

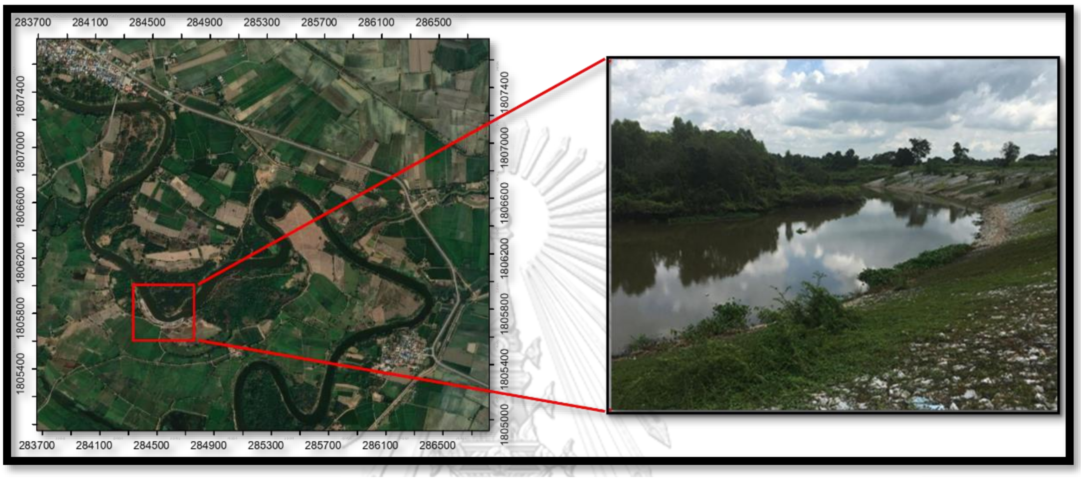

Figure 93 Bank protection in reach 24.

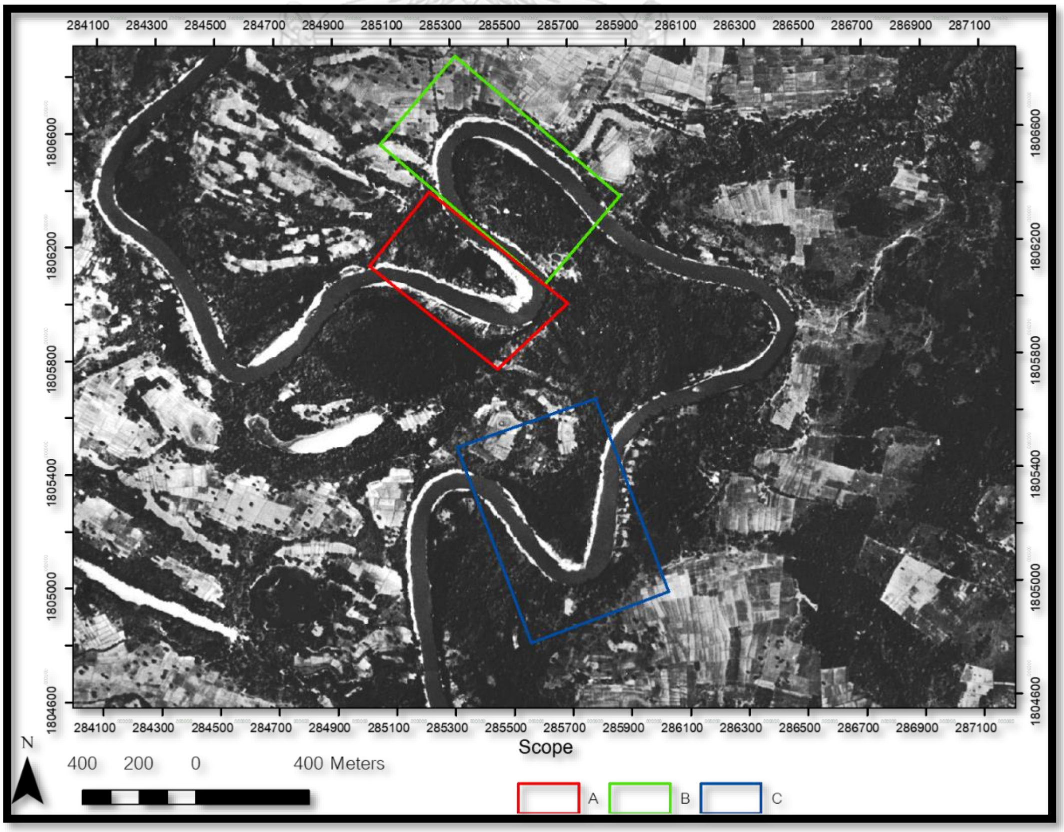

Figure 94 The location of section A, B, C in reach 25.

First, section A has an alteration in terms of sinuosity index. Figure 95 shows the sinuosity index value of scope A in 5 different periods: 1952, 1988, 1992, 2006, and 2020. According to the graph, Y-axis is the Sinuosity index value, and X-axis is a year. The sinuosity index dramatically decreased from 3.271 in 1952 to 2.04 in 1988. Then, it decreased to 1.85 in 2020. In addition, figure 96 shows the boundary of the channel in scope A in 4 different periods: 1952, 1992, 2006, and2020.

It can be seen that this meander loop had retracted to flood plain from 1952 to 2006. It has stable after 2006.

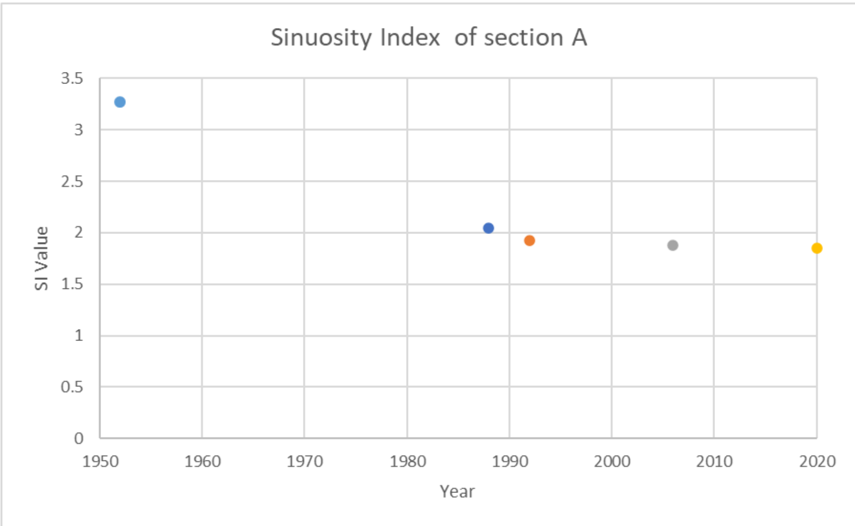

Figure 95 The graph of Sinuosity index of section A .

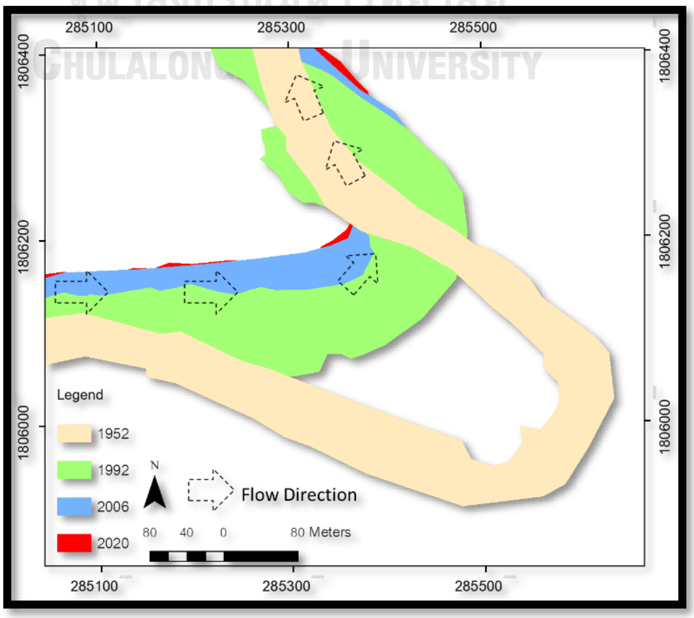

Figure 96 The boundary of the channel in scope A in 4 different periods: 1952, 1992, 2006, and 2020.

Second, section B that displayed in Figure 93, has sand mining in the Chi River. This sand mining has affected geomorphic index value that is measured by widening rate and migration rate and hydrogeomorphology in term of bed substrate. Station 602 has a widening rate of 11.8 meters per year in the period 2006 to 2020 and a migration rate that is measured about 6.64 meters per year in the period 2006 to 2020. Moreover, the sand mining bar has eroded a point bar about 32,336 square meter that was measured in 2020. In addition, figure 97 shows the boundary of the channel in scope B in 2 different periods: 2006 and 2020. It can be seen that channel width has extended.

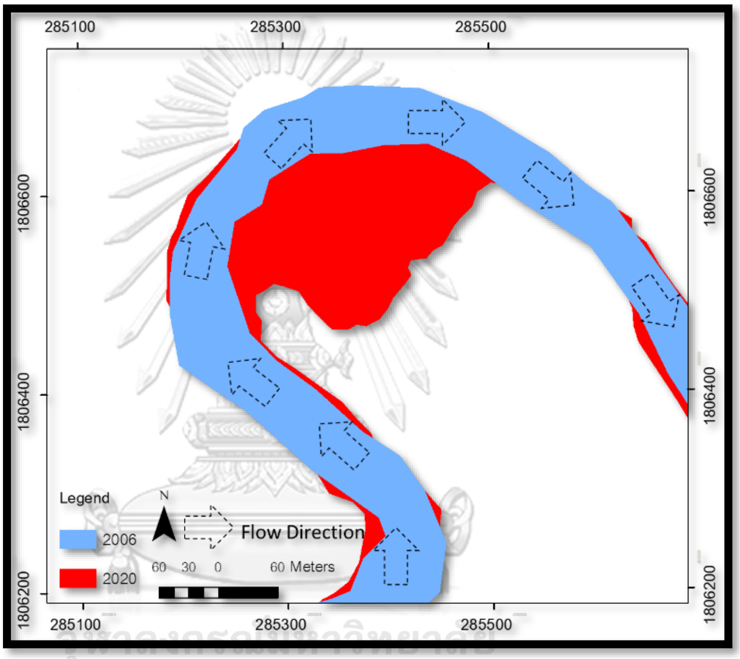

Figure 97 The boundary of the channel in section B in 2 different periods: 2006 and 2020.

Third, section c has meander loop changes. Figure 98 shows the boundary of this meander loop in 5 different periods: 1952, 1992, 2006, and 2020. It can be seen that the meander loop has migrated to the west.

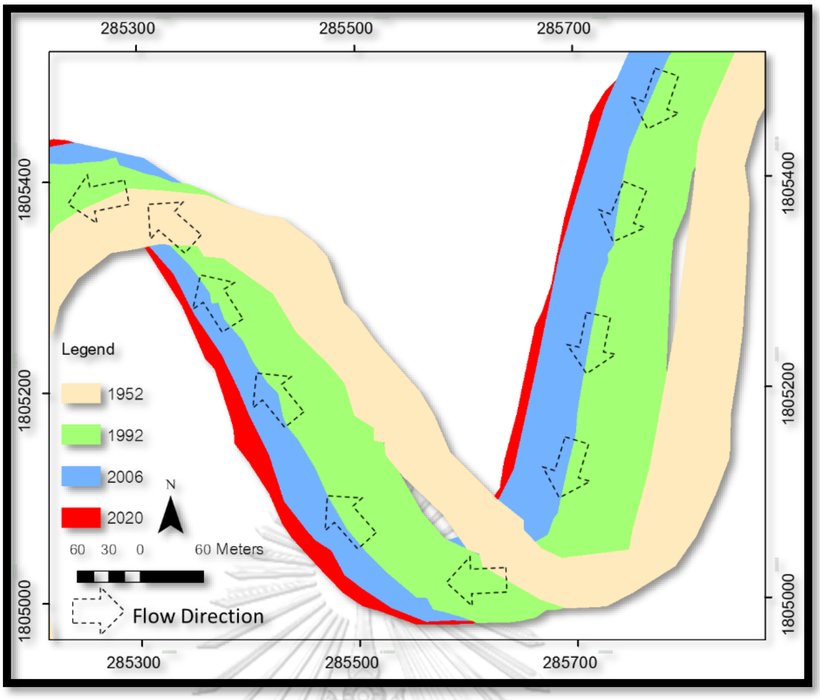

Figure 98 The boundary of the channel in Section C in 4 different periods: 1952, 1992, 2006, and 2020.

Chapter 6: Conclusion & Suggestion

6.1 Conclusion

The study of hydromorphological changes of Chi river in Khon Kaen and adjacent areas was carried out using the result from the analysis in remote sensing data and field investigation. Basically, the geomorphological map was the first step to evaluate the hydromorphological changes based on the aerial photograph interpretation. As a result, the change of flood boundary that analyzes three mega-flood events reveals that the study area has both flood extension and flood decreasing areas. Next, the geomorphic index measured three indices: Sinuosity index, channel width, and migration rate reveal that high geomorphic index alteration will correspond with areas with high artificial distribution levels. Next, the Morphological Quality Index used to evaluate hydromorphological conditions ranges from 0.84 to 0.63, indicating that the area owns a degree of alteration from minor to moderate alteration. Finally, the degree of asymmetry of the channel reveals that the station that has the extreme of asymmetry isn't the station that has the highest alteration. But it is the upstream station that nears the dam.

6.1.1 Geomorphological map

This thesis selects The GUS method (Belletti et al., 2015) for creating a geomorphological map. In study area has only four macro units: Baseflow, Emergent sediment, Riparian Zone, and Floodplain aquatic zone. This thesis produced geomorphological maps in two periods: 1952 and 2020. According to the map, it can be seen that these two maps have three significant differences: the number of emergent sediments, the number of artificial lakes, and the boundary of the maximum flood. First, the number of emergent sediments reduced from 158 bars in 1952 to 7 bars in 2020. Second, many abandoned channels in 1952 have been modified into artificial lakes. It has an artificial lake about lakes covering square meters. Finally, the changing of the maximum flood boundary will describe in 6.1.2

For the downstream area of the irrigation dam, the downstream damming's sediment supply comes from the main channel and the creek and agriculture zone.

6.1.2 Changing of maximum flood boundary

This thesis compared the boundary of maximum flood from three mega-flood events: 1978 mega-flood covering 189.09 square kilometers, 2000 mega-flood covering 164.66 square kilometers, and 2011 covering 193.79 square kilometers. It can be divided the changing flood boundary into six areas: Flooding in 1978 area covering 39.27 square kilometers, Flooding in 1978 and 2000 area covering 6.98 square kilometers, Flooding in 2000 and 2011 area covering 14.84 square kilometers, Flooding in 2011 covering 36.11 square kilometers, Flooding in 1978, 2000 and 2011area covering 94.61 square kilometers and None flooding area covering the rest of study area.

As a result, it may be concluded that the maximum flood boundary responds to man-made construction. The flooding area in scope 1 has reduced about 0.76 square kilometers after modification abandoned channel to an artificial lake. While, the flooding area in scope 3 has extended after installing a drainage system.

6.1.3 Hydromorphological condition

Hydromorphological condition was evaluated by the Morphological Quality Index (Rinaldi et al., 2013). The MQI score (Figure 58) ranges from 0.84 to 0.63, classified as a morphological quality class into 2 classes: Good class and Moderate class. The moderate class consists of only 4 reaches 10, 11, 21 and 24 while other reaches are classified as Good Class. The MQI score indicates the study area has minor to moderate alteration and disturbance from human activities.

6.1.4 Geomorphic Index

This thesis measured three geomorphic indices: channel width, widening rate, and migration rate. These indices were calculated in the dry season. First, channel width was measured in 5 periods: 1952, 1988, 1992, 2006, and 202 that ranges from 11.1 meters to about 225.32 meters. Next, the widening rate was measured in 4 periods: 1952-1988, 1988-1992, 2006-2020, and 2020 that ranges from -5.17 meters per year to 11.08 meters per year. Finally, the migration rate was measured from the middle channel in 4 periods: 1952-1988, 1988-1992, 1992-2006, and 2006 to 2020 that ranges from 0.001 meters per year to more than 90 meters per year.

6.1.4.1 Relationship between MQI score and Geomorphic index alteration.

The results found that high geomorphic index alteration will correspond with many areas altered by artificial construction (low score of MQI). Station 602, sand mining, has a widening rate of 11.8 meters per year, while the average absolute widening rate was calculated by only 0.5023 meters per year. The average migration rate was just only 0.72 meters per year for migration rate, but station 467, that area has a dam across the Chi River, has a migration rate of more than 90 meters per year during construction. Moreover, this station's SI value had changed from 1.53 (in 1952) to 1.02 (in 2020).

6.1.4.2 Comparison between upstream area and downstream area of irrigation dam

For migration rate, the upstream area has no significant alteration. In contrast, the average migration rate of the downstream area dramatically increased from 0.46 meters per year from 1952 to 1988 to about 2.26 meters per year from 1988 to 1992 (construction period). Then, it decreased to 0.90 meters per year in the period from 2006 to 2020.

It does not have a significant alteration of the downstream area’s widening rate construction period for widening rate. However, the downstream area’s widening rate reduced after the dam had operated in 1992.

Thus, it may be concluded that the irrigation dam in the study area has influenced the migration rate of the upstream area in the dam construction period and has reduced the downstream’s widening rate.

6.1.5 Asymmetry of channel

Asymmetry of channel was evaluated from the cross-sectional data collected from 5 different locations in Chi river. It can be seen that the downstream location that has the highest percentage of artificiality shows none of degree of asymmetry of the channel, while the upstream station that has no the highest percentage of artificiality has the most degree of asymmetry of the channel. Thus, it can be assumed that location: upstream and downstream of artificial elements is one of essential factors that influence the channel's asymmetry.

6.2 Suggestion

Five suggestions arisen from this thesis are as follows:

1. Making an artificial lake is one way to mitigate damage from the flood. Moreover, the lake can be used in the dry season. In addition, Figure 99 shows the recommended location that should be investigated in more detail of subsurface geology for making an artificial lake.
2. The erosional and depositional patterns of reach 24 should be investigated in more detail because the sand mining and the bank protection have alerted the bed substrate and the degree of erosion and deposition.
3. This study confirms the need for hydro-geomorphological research to be applied for future prediction and protection from flooding and river restoration.

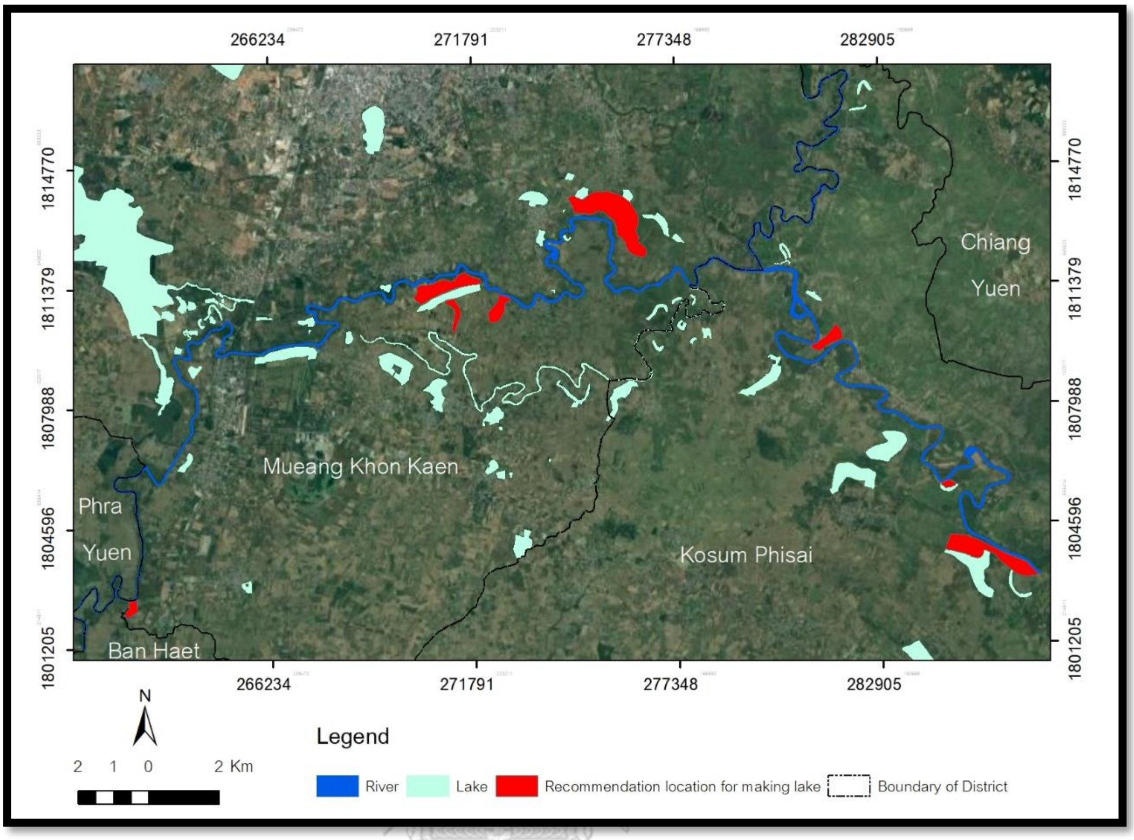

Figure 99 The location of recommendation location for making an artificial lake.

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Appendix

Appendix A. MQI Evaluation form (Rinaldi et al., 2013)

Class	**Detail**	**Score**
Artificiality		
A1: Upstream alteration of flow		
A	No significant alteration (≤10%) of channel-forming discharges and with return interval>10 years	0
B	Significant alteration (>10%) of discharges with return interval>10 years or release of increased low flows downstream dams during dry seasons	3
C	Significant alteration (>10%) of channel-forming discharges	6
A2: Upstream alteration of sediment		
A	Absence or negligible presence of structures for the interception of sediment fluxes (dams for drainage area ≤5% and/or check dams/abstraction weirs for drainage area ≤33%)	0
B1	Dams (area 5-33%) and/or check dams/weirs with total bedload interception (area 33-66%) and/or check dams/weirs with partial interception (area >66%)	3
B2	Dams (area 33-66%) and/or check dams/weirs with total bedload interception (area>66%)	6
C1	Dams for drainage area >66%	9
C2	Dam at the upstream boundary of the reach	12
A3: Alteration of flow (in reach)		
A	No significant alteration (≤10%) of channel-forming discharges and with return interval>10 years	0
B	Significant alteration (>10%) of discharges with return interval>10 years	3
C	Significant alteration (>10%) of channel-forming discharges	6
A4: Alteration sediment discharge		

A	Absence of structures for the interception of sediment fluxes (dams, check dams, abstraction weirs)	0
B	*Channels with S≤1%*:consolidation check dams and/or abstraction weirs ≤1 every 1000 m *Steep channels (S>1%)*:consolidation check dams ≤1 every 200 m and/or open check dams	4
C	*Channels with S≤1%*:consolidation check dams and/or abstraction weirs >1 every 1000 m *Steep channels (S>1%)*: consolidation check dams >1 every 200 m and/or retention check dams Or presence of a dam or artificial reservoir at the downstream boundary (any bed slope)	6
A5: Crossing Structure		
A	Absence of crossing structures (bridges, fords, culverts)	0
B	Presence of some crossing structure (≤1 every 1000 m in average in the reach)	2
C	Presence of many crossing structure (>1 every 1000 m in average in the reach)	3
A6 Bank protections		
A	Absence or localized presence of bank protections (≤5% total length of the banks)	0
B	Presence of protections for ≤33% total length of the banks (sum of both banks)	3
C	Presence of protections for >33% total length of the banks (sum of both banks)	6
A7: Artificial levees		
A	Absent or set-back levees, or presence of close and/or bank-edge levees ≤5% bank length	0
B	Bank-edge levees ≤50%, or ≤33 in case of total of close and/or bank edge>90%	3

C	Bank-edge levees >50%, or >33% in case of total of close and/or bank edge>90%	6
A8: Artificial changes of river course		
A	Absence of artificial changes of river course in the past (meanders cut-off, channel diversions, etc.)	0
B	Presence of changes of river course for ≤10% of the reach length	2
C	Presence of changes of river course for >10% of the reach length	3
A9: Other bed stabilization structures		
A	Absence of structures (bed sills/ramps) and revetments	0
B	Sills or ramps (≤1 every d) and/or revetments ≤25% permeable and/or ≤15% impermeable	3
C1	Sills or ramps (>1 every d) and/or revetments ≤50% permeable and/or ≤33% impermeable	6
C2	Revetments >50% permeable and/or >33% impermeable	8
A10: Sediment removal		
A	Absence of significant sediment removal activities during the last 20 years	0
B	Localized sediment removal activities during the last 20 years	3
C	Widespread sediment removal activities during the last 20 years	6
A11: Wood removal		
A	Absence of removal of woody material at least during the last 20 years	0

B	Partial removal of woody material during the last 20 years	2
C	Total removal of woody material during the last 20 years	5
A12: Vegetation management		
A	No cutting interventions on riparian (last 20 years) and aquatic vegetation (last 5 years)	0
B	Selective cuts and/or clear cuts of riparian vegetation ≤50% of the reach and partial or no cutting of aquatic vegetation, or no cutting of riparian but partial or total cutting of aquatic vegetation	2
C	Clear cuts of riparian vegetation >50% of the reach, or selective cuts and/or clear cuts of riparian vegetation ≤50% of the reach but total cutting of aquatic vegetation	5
Geomophological Functionality		
F1: Longitudinal continuity in sediment and wood flux		
A	Absence of alteration in the continuity of sediment and wood	0
B	Slight alteration (obstacles to the flux but with no interception)	3
C	Strong alteration (discontinuity of channel forms and interception of sediment and wood)	5
F2: Presence of a modern floodplain		
A	Presence of a continuous (>66% of the reach) and wide modern floodplain	0
B1	Presence of a discontinuous (10÷66%) but wide modern floodplain or >66% but narrow	2
B2	Presence of a discontinuous (10÷66%) and narrow modern floodplain	3

C	Absence of a modern floodplain or negligible presence (≤10% of any width)	5
F3: Hillslope - river corridor connectivity		
A	Full connectivity between hillslopes and river corridor (>90%)	0
B	Connectivity for a significant portion of the reach (33÷90%)	3
C	Connectivity for a small portion of the reach (≤33%)	5
F4: Processes of bank retreat		
A	Bank erosion occurs for >10% and is distributed along >33% of the reach	0
B	Bank erosion occurs for ≤10%, or for >10% but is concentrated along ≤33% of the reach or significant presence (>25%) of eroding banks by mass failures	2
C	Complete absence (≤2%) or widespread presence (>50%) of eroding banks by mass failures	3
F5 : Presence of a potentially erodible corridor		
A	Presence of a wide potentially erodible corridor (EC) for a length >66% of the reach	0
B	Presence of a potentially EC of any width for 33-66% of the reach or for >66% but narrow	2
C	Presence of a potentially EC of any width but for ≤33% of the reach	3
F6: Bed configuration - valley slope		
A	Bed forms consistent with the mean valley slope or not consistent for ≤33% of the reach	0
B	Bed forms not consistent with the mean valley slope for 33-66% of the reach	3

C	Alteration of bed forms for >66% of the reach	5
F7 : Planform pattern		
A	Absence (≤5%) of alteration of the natural heterogeneity of geomorphic units and channel width	0
B	Alterations for a limited portion of the reach (≤33%)	3
C	Consistent alterations for a significant portion of the reach (>33%)	5
F8: Presence of typical fluvial landforms in the floodplain		
A	Presence of floodplain landforms (oxbow lakes, secondary channels, etc.)	0
B	Presence of traces of landforms (abandoned during the last decades) but with possible reactivation	2
C	Complete absence of floodplain landforms	3
F9 : Variability of the cross-section		
A	Absence (≤5%) of alteration of the cross-section natural heterogeneity (channel depth)	0
B	Presence of alteration (cross-section homogeneity) for a limited portion of the reach (≤33%)	3
C	Presence of alteration (cross-section homogeneity) for a significant portion of the reach (>33%)	5
F10 : Structure of the channel bed		
A	Natural heterogeneity of bed sediments and no significant armouring and/or clogging	0
B	Evident armouring or clogging for ≤50% of the reach	2

C1	Evident armouring or clogging (>50%), or burial (≤50%), or occasional substrate outcrops	5
C2	Evident burial (>50%), or substrate outcrops or alteration by bed revetments (>33% of the reach)	6
F11: Presence of in-channel large wood		
A	Significant presence of large wood along the whole reach (or "wood transport" reach)	0
B	Negligible presence of large wood for ≤50% of the reach	2
C	Negligible presence of large wood for >50% of the reach	3
F12: Width of functional vegetation		
A	High width of functional vegetation	0
B	Medium width of functional vegetation	2
C	Low width of functional vegetation	3
F13: Linear extension of functional vegetation and presence of emergent aquatic macrophytes		
A	Riparian vegetation >90% of maximum length, or riparian vegetation>33% and significant presence of emergent aquatic vegetation (low-energy channels)	0
B	Riparian vegetation 33÷90%, or riparian vegetation >90% but very limited presence of aquatic vegetation, or riparian vegetation ≤33% but significant presence of aquatic vegetation	3
C	Riparian vegetation ≤33%, or <90% but very limited presence of aquatic vegetation	5
Channel Adjustment		

CA1: Adjustment in channel pattern		
A	Absence of changes of channel pattern since 1930s - 1960s	0
B	Change to a similar channel pattern since 1930s - 1960s	3
C	Change to a different channel pattern since 1930s - 1960s	6
CA2 : Adjustments in channel width		
A	Absent or limited changes (≤15%) since 1930s - 1960s	0
B	Moderate changes (15÷35%) since 1930s - 1960s	3
C	Intense changes (>35%) since 1930s - 1960s	6
CA3: Bed-level adjustments		
A	Negligible bed-level changes (≤0.5 m)	0
B	Limited to moderate bed-level changes (0.5÷3 m)	4
C1	Intense bed-level changes (>3 m)	8
C2	Very intense bed-level changes (>6 m)	12

Appendix B Confinement condition and MQI

All Confinement Condition	Confined Condition	Partly-Unconfined condition
F1, F6, F9, F10, F11, F12, F13, A1, A2, A3, A4, A5, A6, A9, A10, A11, A12 CA1, CA2, CA3	F3 F6	F2, F4, F5, F7, F8,A7, A8

Appendix C Classification of MQI indicator in Hydromorphological Quality aspect

		Functionality	**Artificiality**	**Channel Adjustment**
Hydrological regime	**Quantity and dynamic of water flow**	**F1**	**A1 A2 A3 A4**	
	Connection to ground water	None		
River Continuity	Longitudinal	F1	A1 A2 A3 A4 A5	
	Lateral	F3 F4 F5	A6 A7	
Morphological	River Depth and Width Variation	F6 F7 F10	A6 A8 A9	CA1 CA2 CA3
	Substrate	F10 F11	A9 A10 A11	
	Flood Plain	F2 F8	A8	
	Riparian Zone	F5 F9 F11 F12 F13	A12	

Appendix D Channel width of each station

Station	Channel Width (Meter)				
	1952	1988	1992	2006	2020
0	26.97536	44.99935	44.9051	52.14185	59.13228
1	21.28372	35.6128	35.6264	47.28263	40.4379
2	28.38964	36.09855	36.2557	42.60878	38.8768
3	29.35545	33.55398	33.7244	44.34722	37.7918
4	27.92205	33.76546	33.7017	50.31911	46.03982
5	30.2115	35.44743	35.2769	29.44366	39.18858
6	37.18606	37.07384	37.3543	48.26225	49.09085
7	38.86869	40.46129	38.5064	45.68863	46.07949
8	28.23656	36.33744	37.5505	41.2745	45.2278
9	28.2692	36.4838	37.2156	44.87551	46.91429
10	22.52601	35.26652	32.8845	49.34556	50.35731
11	24.56558	27.22707	28.4533	42.32522	39.33613
12	24.3613	31.20807	31.2626	35.7172	36.88589
13	58.28546	45.72451	45.8508	46.20828	39.98211
14	22.43717	35.4041	34.9757	37.51214	27.71726
15	30.97195	31.44626	31.5278	40.11649	35.44944
16	28.28552	30.26344	30.3129	40.135	40.43958
17	23.63498	38.06932	38.0018	44.01928	41.84881
18	33.367	31.98667	31.7517	43.59212	46.06722
19	33.61426	34.79363	35.1534	46.94923	43.99128
20	40.58865	38.51059	38.8178	44.16405	46.37101
21	36.29519	38.50132	38.1583	44.83079	48.2015
22	32.83733	40.34368	37.9189	44.00188	53.8015
23	23.60547	27.72173	27.6133	32.47365	30.70527
24	19.86656	40.36314	40.3004	40.39657	52.26288
25	27.32678	28.39157	28.9123	38.42589	41.38575
26	26.12388	31.83397	31.7278	40.01047	45.50267
27	25.07511	41.22027	40.8905	46.87189	44.4696
28	21.25533	33.23455	35.3105	50.05712	47.5463
29	23.69652	42.97763	40.4	42.9851	34.16939

30	22.4674	31.96325	32.1143	37.39434	43.09611
31	11.19581	29.23225	29.7836	37.8681	35.24063
32	20.88355	38.63081	38.9791	40.7958	39.67229
33	32.78034	41.73944	41.9684	52.62813	46.66442
34	28.047	38.70386	38.157	39.26489	42.636
35	18.6575	29.68815	29.2805	43.1287	44.53405
36	12.16114	33.3478	33.147	40.72325	45.14635
37	36.42067	44.19323	44.0497	47.30946	44.37337
38	13.7169	33.05424	33.4646	42.67436	49.36758
39	25.01435	42.07178	41.8653	42.43369	51.83054
40	26.75275	51.69672	51.7899	47.72929	40.91938
41	22.38014	33.82955	34.2781	47.19999	39.39398
42	57.85087	49.78774	50.0866	52.07055	51.7222
43	24.56789	43.6024	43.5507	40.66111	42.81921
44	26.50936	34.41236	34.6425	40.94073	34.64713
45	17.85394	25.93936	25.9877	32.95868	35.20618
46	19.22459	30.70941	31.9762	30.72528	41.82593
47	30.61004	36.23062	36.536	47.14704	48.73602
48	29.01956	37.06425	37.6736	41.86951	42.6628
49	35.27945	35.77956	38.5542	48.95626	44.28398
50	27.47404	41.84063	42.2613	44.74652	43.25433
51	21.1325	36.95298	36.7864	24.07228	38.4037
52	25.58128	30.03874	30.024	32.73355	38.51471
53	17.6946	37.37478	37.7202	43.40048	41.2848
54	20.32345	42.18004	37.3945	51.35139	50.95591
55	23.79618	40.55708	37.0108	49.45354	45.87363
56	23.48818	34.25797	34.8327	43.31614	43.33254
57	19.77864	37.54329	37.2597	38.02537	42.79797
58	26.97693	37.65256	38.5322	42.21373	33.77921
59	31.3495	35.43714	37.0471	41.81691	41.99258
60	38.55993	48.78279	48.9211	43.6435	47.76631
61	25.93107	41.48965	41.1208	42.54973	41.18934
62	19.59532	33.38162	33.9662	39.47622	36.14999
63	20.38022	41.13675	39.4528	48.55926	46.17564

64	19.84383	38.60951	35.202	48.07767	38.65334
65	22.73431	42.25527	42.5742	40.96119	42.86443
66	16.08777	40.79811	37.8295	47.9309	42.77258
67	26.07167	37.1422	35.5345	45.39921	41.43392
68	22.49854	37.05168	37.6588	40.55282	40.86354
69	23.95238	35.99516	36.1308	42.36419	32.68376
70	26.61584	35.71431	35.7247	42.26028	40.12542
71	20.56964	37.26173	37.6755	44.7789	33.4969
72	33.36197	33.68396	33.946	41.25067	37.11743
73	25.57372	39.43954	39.3663	39.4747	36.58271
74	28.0273	33.48452	33.4619	41.45664	37.10341
75	21.86673	45.77283	46.4178	34.98163	29.24325
76	31.4473	45.42689	43.052	44.371	36.74605
77	31.51775	43.17231	42.4231	44.58209	44.56211
78	23.17415	43.69662	39.8187	46.39457	37.75866
79	27.6425	43.85521	38.9047	41.43647	46.26147
80	28.21858	41.48056	39.3788	35.76599	42.63493
81	24.61776	34.79111	33.0786	42.01897	41.70546
82	19.14929	43.03546	43.5691	41.47351	41.43933
83	36.01227	42.50446	42.4067	47.41291	37.5898
84	24.90554	41.15066	41.2647	43.02062	47.53426
85	26.10757	45.32173	45.3018	55.78921	48.58832
86	37.50844	45.09735	43.993	52.96235	50.68313
87	27.71651	33.92004	34.2242	45.7802	42.91782
88	36.3932	27.83216	28.1249	55.17464	51.19547
89	32.25897	46.20408	43.2019	47.26484	52.17457
90	28.78251	38.56294	33.6991	41.74812	38.09236
91	29.61543	42.13485	39.2542	42.3782	32.98496
92	32.30636	43.86468	41.7263	49.59277	47.79249
93	30.14535	40.03465	37.0352	51.30853	45.1301
94	19.27856	33.02675	32.2235	43.97036	46.95873
95	24.48295	41.3251	41.5106	52.58777	52.5584
96	36.89257	34.60251	34.7198	46.62413	45.56688
97	24.04433	37.11268	37.1059	45.23608	45.98032

98	21.3755	36.50525	36.5033	45.77443	43.95212
99	32.52647	39.979	40.0558	52.65231	46.43637
100	34.81643	42.0823	42.6179	48.21343	46.17964
101	30.33668	47.69212	47.9289	50.3824	48.80966
102	67.98159	45.58616	45.3903	77.60616	76.78828
103	32.89471	47.26697	45.9019	58.90692	55.75886
104	36.98052	40.89263	40.7196	43.0082	42.57567
105	20.36742	39.47839	40.0503	49.36029	52.18512
106	26.64006	30.95382	31.0344	44.33401	49.57806
107	29.8152	43.06017	41.3312	52.07719	45.2504
108	33.90753	40.06692	39.9893	47.33561	39.94229
109	38.39784	58.33498	58.7656	54.34943	49.79303
110	13.96448	66.06071	62.914	49.37911	45.5395
111	15.26647	69.97477	70.1298	56.67052	48.7983
112	27.22522	57.19047	57.3965	53.97407	46.70999
113	18.20228	37.89816	37.9718	40.6059	39.5186
114	23.63427	29.46038	29.3155	51.87913	44.18128
115	21.45846	39.92463	40.1432	46.5026	39.9305
116	27.00072	44.84054	44.8535	47.44067	40.34172
117	21.86819	34.24688	31.9323	44.76198	43.46858
118	29.21043	35.82756	35.9365	41.98661	42.63045
119	36.16593	38.80781	36.064	45.09611	41.80693
120	30.09351	37.33036	34.2066	41.73215	37.04048
121	25.03819	45.01855	42.927	53.02116	40.68456
122	33.4672	41.61251	41.4171	50.8562	48.65029
123	28.05419	41.93666	41.0895	47.8929	39.02194
124	31.9008	40.02918	34.9115	44.25908	39.60612
125	28.15499	35.7935	34.3166	46.42028	44.16529
126	18.64977	36.7276	38.9101	48.86686	43.65015
127	29.50278	46.30134	46.3244	43.08517	43.4404
128	32.80246	59.17349	59.4609	52.03836	46.08113
129	26.36786	41.05324	40.905	55.62291	52.82075
130	30.85657	38.65204	38.8462	47.29015	35.63086
131	20.69978	40.5762	40.6513	48.85165	40.31505

132	24.28051	48.61633	48.5912	55.86395	42.54668
133	33.13465	41.74933	41.8729	49.70367	43.74948
134	23.3024	42.74108	40.4453	39.36144	34.71876
135	23.79889	40.80727	40.6513	43.15865	40.45244
136	28.12794	32.67523	28.9438	42.87129	38.1993
137	25.5872	40.79275	37.1709	38.24926	40.54182
138	31.29679	41.05679	40.9508	52.0973	49.75432
139	22.5333	36.8201	34.2783	41.42001	41.12003
140	17.58817	38.21013	36.4984	44.17835	35.4324
141	21.7601	29.00623	30.7512	45.51631	42.56126
142	23.94223	33.39078	30.34	36.54035	31.53833
143	32.49205	35.93812	36.4114	48.61914	39.27079
144	28.06284	29.99966	30.4216	42.2098	34.11963
145	22.045	33.74173	33.4698	44.85338	40.54505
146	31.87454	37.74012	34.7669	40.17654	39.60097
147	28.29786	27.54877	27.2083	39.39125	41.7175
148	32.4128	30.91317	28.6363	43.50078	43.34178
149	26.00048	34.63436	35.1554	52.71717	39.06579
150	32.98312	35.9202	35.9202	45.78426	37.53815
151	30.12289	41.26148	39.8414	52.1509	38.29338
152	27.35086	33.2088	33.9393	40.18476	35.73567
153	27.02607	37.63544	37.4853	46.79343	37.31965
154	32.8256	52.16189	49.8347	59.84602	54.21031
155	26.92359	42.0528	41.9315	47.79187	42.87895
156	20.65803	32.00756	31.0498	45.7327	39.13249
157	32.40219	46.27368	42.5331	59.2172	50.43664
158	25.38751	54.02771	53.731	49.57828	41.72121
159	29.69343	47.01013	46.4531	57.93935	44.58284
160	30.86823	39.26661	40.1119	53.04374	43.06901
161	45.47404	35.97952	36.7834	37.64207	48.80045
162	39.35828	37.65449	37.5994	53.42848	45.71846
163	25.11587	36.88859	33.3002	40.90879	35.53013
164	24.34006	28.32771	25.3062	39.31065	34.2955
165	29.38248	39.46651	34.9783	47.12423	30.87041

166	23.90704	29.60741	28.3649	42.1444	35.38915
167	29.78646	36.28838	35.4814	45.27975	40.94508
168	28.78944	32.26059	33.8667	50.80869	44.36064
169	27.10704	44.47468	38.4787	43.95212	42.96723
170	39.75269	47.64265	46.6843	55.98215	47.84205
171	35.23974	44.63251	43.5747	39.14587	44.64004
172	42.3509	41.8216	41.8216	49.294	45.79719
173	27.57941	42.273	43.8908	40.54261	37.70008
174	28.23984	41.97493	41.5327	42.1005	43.30497
175	31.49406	32.84955	33.0662	32.62244	37.73159
176	29.88292	38.0743	38.0743	49.2703	35.21274
177	27.99473	38.67305	34.5541	42.2828	39.19425
178	40.01483	36.2389	36.2389	47.4412	37.52964
179	35.1292	40.70448	40.9986	46.52405	47.30855
180	31.57291	33.74362	33.1308	45.08747	49.7076
181	41.0814	48.16961	48.8287	58.72637	42.62354
182	38.64671	48.58812	46.4303	60.56177	49.91948
183	29.55835	46.89941	47.2407	64.09549	45.39183
184	34.68015	46.89625	47.0516	63.22326	50.27799
185	34.36776	40.44542	40.7064	46.86992	43.98787
186	29.28715	28.77339	29.9796	47.72023	44.85
187	33.1	33.19836	34.2376	38.6235	48.58
188	39.21	49.80681	49.6672	62.181	56.26
189	30.75	37.87301	37.9802	36.95591	42.65
190	33.54	36.63074	37.2495	39.78016	39.95
191	30.57	44.18524	44.2446	47.46816	42.78
192	25.14	45.62751	46.6434	49.00038	50.24
193	29.4	43.10119	43.4053	52.01329	44.77
194	34.94	45.46837	45.5227	52.69038	47.85
195	32.31	55.39236	54.683	56.19701	50.78
196	28.76	48.60096	48.9965	53.32911	42.14
197	32.71	47.81801	48.3973	50.36869	45.75
198	38.77	38.20734	38.7117	49.58886	38.84
199	37.94	42.53837	41.9646	55.04894	36.2

200	41.19	43.62651	43.8742	49.5181	39.95
201	37.48	49.72871	50.379	58.96292	48.37
202	27.75	50.09275	50.1346	58.73691	49.01
203	35.47	44.80416	45.0032	47.38634	46.08
204	32.41	38.57283	38.5106	49.36732	45
205	37.06	48.60688	48.6834	50.49264	49.81
206	36.2	50.08007	50.3841	52.88248	47.11
207	31.88	42.74268	42.7167	43.2375	44.25
208	33.98	44.19064	44.1845	43.92456	43.61
209	38.64	41.0554	41.2048	51.11457	46.99
210	36.92	46.23965	46.4265	50.46132	48.51
211	28.39	36.8156	36.9031	42.13752	38.29
212	20.2	38.60272	38.8353	44.49692	44.02
213	27.65	38.70586	38.3333	47.84247	46.04
214	64.45	58.88984	59.6087	65.13399	49.07
215	49.77	36.41485	38.2868	49.53706	45.11
216	47.76	47.24377	49.7581	60.29135	51.98
217	51.68	53.71472	54.0781	61.70131	50.11
218	27.98	51.80981	52.2516	54.85831	43.81
219	36.78	45.30163	45.1972	45.94314	46.4
220	36.95	30.34763	30.5236	44.49078	41.54
221	59.4	27.21944	26.9082	43.01153	36.78
222	47.95	50.96012	51.1609	53.1814	40.76
223	49.27	36.30889	36.2138	46.42527	40.31
224	31.15	31.02205	30.6611	43.05983	45.65
225	29.15	36.07703	36.0174	44.46381	44.89
226	27.7	31.6566	33.2535	43.48382	48.03
227	20.7	29.48263	29.5435	49.41166	40.04
228	46.65	47.81198	47.9721	58.90633	51.7
229	47.6	42.41331	42.5352	50.94366	47.72
230	39.07	50.1345	49.8853	63.55907	52.32
231	47.73	63.73004	64.3349	62.42182	61.67
232	39.03	62.59076	63.6144	62.60008	60.12
233	39.75	77.72318	77.1853	68.64559	57.06

234	40.4	41.0684	40.5567	51.3704	47.87
235	25.7	31.92991	32.3023	50.62948	46.53
236	39.14	39.18006	39.3438	57.09751	47.51
237	41.17	39.6832	39.9088	55.79989	48.04
238	35.12	42.79738	42.8102	52.0493	47.91
239	43.9	42.10711	43.3588	47.70235	49.36
240	39.74	39.3793	39.3622	55.46944	46.33
241	35.86	40.21376	41.2464	46.98334	40.63
242	38.15	36.54825	37.5215	46.11468	48.78
243	57.66	44.17688	45.2163	51.55417	53.09
244	41.46	43.94768	45.2958	54.79459	51.55
245	40.66	31.03081	32.4399	54.09203	41
246	39.33	42.22419	42.7502	45.24351	48.11
247	38.1	49.01941	48.3908	53.41759	52.43
248	40.55	48.75034	49.1346	59.39934	49.48
249	48.17	40.7501	40.694	52.96009	54.92
250	36.64	43.56918	43.7342	55.04771	58.7
251	29.82	38.7248	38.851	58.8867	44.85
252	44.92	49.93985	50.708	63.77359	54.29
253	34.29	48.24523	48.5995	53.58962	53.65
254	36.71	41.35529	41.311	54.57627	50.43
255	34.78	49.75181	49.7217	49.49762	52.53
256	34	41.82638	42.01	47.5269	48.3
257	40	44.75581	44.9805	47.71653	51.21
258	45.42	40.84201	42.1151	51.17258	44.4
259	40.64	49.33527	49.1915	57.15886	54.2
260	58.1	57.59755	57.4211	62.92058	61.65
261	53.21	49.83113	51.3174	54.92751	54.63
262	53.45	41.36767	41.5048	50.19949	47.21
263	41.14	42.61848	42.6431	49.28006	42.31
264	34.54	44.78332	44.7374	57.61854	46.18
265	49.39	37.77803	37.0864	53.77455	57.53
266	45.73	48.5176	48.8531	65.88283	51.56
267	42.29	55.37562	55.0882	62.01525	58.77

268	43.84	48.98604	49.0829	50.14564	53.49
269	50.04	43.85173	44.2517	56.73423	45.38
270	51.31	53.0265	52.4085	52.36654	50.52
271	44.95	68.22707	69.5129	75.52221	73.93
272	54.98	63.38125	64.7091	80.89287	50.77
273	48.87	48.73837	48.7882	58.83465	52.51
274	53.61	61.71549	61.4688	65.6369	63.83
275	48.73	53.02951	53.952	65.37052	61.01
276	47.26	55.87735	55.2902	51.73237	59.72
277	40.06	43.41817	43.0209	51.79026	28.8
278	38.27	46.63175	46.529	55.97812	49.34
279	37.49	54.87931	54.8266	64.93346	56.56
280	32.42	52.08012	52.0749	55.07615	53.59
281	43.41	49.18778	48.4331	53.80813	52.17
282	42.4	47.93205	47.5619	57.54495	61.27
283	45.3	63.13294	62.9697	60.3134	52.71
284	54.74	49.56436	49.454	74.45877	61.41
285	54.21	56.31314	56.3061	62.01336	67.52
286	46.99	57.0844	57.2101	71.94799	59.95
287	37.82	38.06526	37.9347	59.57036	51.86
288	35.29	40.81917	40.4748	55.36059	51.93
289	40.34	42.46296	42.3987	48.41266	41.4
290	43.49	41.82692	41.8789	51.56287	40.24
291	32.35	44.9761	45.8609	41.10031	47.07
292	49.12	48.00292	49.2251	46.6408	57.89
293	39.85	52.90101	52.7579	69.72808	56.98
294	37.6	49.72259	49.7283	58.39463	55.92
295	48.3	46.80467	47.3911	62.3987	62.69
296	43.09	52.65712	51.7273	65.15795	60.08
297	50.6	61.53507	60.9246	68.45109	61.71
298	45.86	51.74407	52.2641	58.86623	57.25
299	44.21	50.56279	50.5821	64.4856	47.44
300	38.65	46.95314	47.025	52.65149	52.41
301	40.46	40.91299	40.731	45.56377	41.77

302	46.74	48.73129	49.623	54.00473	52.2
303	29.4	38.37287	37.904	36.98916	43.63
304	33.44	52.22634	51.6905	56.34738	52.52
305	36.33	45.28565	46.5144	49.41718	54.04
306	49.51	52.5012	51.8371	61.96076	58.49
307	36.91	48.92212	49.8216	64.2909	59.12
308	53.01	65.57091	66.1213	80.64815	58.18
309	47.57	58.59668	58.5495	51.48262	60.75
310	44.66	61.55285	62.4469	64.63172	60.22
311	40.37	58.10471	59.4239	67.15313	62.02
312	40.86	40.61796	41.921	47.59559	51.21
313	35.16	50.72615	50.8069	54.7741	68.22
314	45.61	57.75983	58.1057	60.12475	53.91
315	40.63	57.31122	57.4402	62.86093	53.66
316	45.12	57.70296	57.6211	55.80319	56.45
317	48.13	53.99278	54.5074	62.71574	52.1
318	39.28	70.83753	70.6204	65.63188	57.52
319	38.69	60.24856	61.5948	71.99384	59.28
320	47.16	53.9311	54.0362	60.57711	54.85
321	50.55	40.14673	40.3744	55.94444	50.53
322	38.62	41.50715	41.9648	48.12379	54.69
323	38.61	45.91728	46.0618	56.48392	52.51
324	33.67	44.22498	44.8702	55.38422	47.85
325	45.38	42.55025	42.2337	57.48716	50.31
326	47	35.57921	36.3382	50.65895	44.3
327	49.17	40.78123	40.792	54.5157	44.21
328	49.17	41.20086	40.9385	54.54332	57.81
329	49.75	44.15474	45.8405	53.03511	55.41
330	30.78	36.49191	36.8229	53.17992	48.18
331	39.31	41.66383	42.0137	64.59862	55.74
332	45.74	53.41496	54.7075	60.21146	49.72
333	33.67	38.67184	38.6026	47.91465	47.02
334	33.49	37.04328	37.0559	47.41468	41.94
335	39.67	41.61386	42.7269	55.90154	48.37

336	49.36	54.29433	54.8996	68.67222	65.31
337	43.21	43.68772	44.166	53.75379	52.8
338	46.32	48.40969	48.6291	58.7244	55.14
339	37.38	45.2548	45.5309	63.07683	59.86
340	42.03	44.84431	45.761	55.87517	53.23
341	50.57	49.79159	50.6931	72.95586	59.2
342	37.63	45.94898	46.6682	64.24386	57.04
343	38.37	54.69396	54.4575	58.31442	52.46
344	25.15	44.4078	44.7985	60.58609	58.28
345	48.51	55.41418	56.4717	191.811	207.71
346	58.57	65.83175	66.302	189.0795	162.87
347	50.97	63.57415	63.7586	76.45529	80.66
348	42.97	51.62138	52.1316	77.41163	77.63
349	41.99	47.9298	49.7619	61.7678	90.48
350	29.46	41.15314	40.9711	54.35016	54.48
351	31.03	38.61616	39.8696	51.40597	52.15
352	29.74	33.51434	34.4927	52.38517	50.16
353	39.28	36.77574	36.3402	44.33669	52.19
354	31.73	40.36099	41.1641	45.14035	56.74
355	38.04	56.62996	57.5934	53.69862	55.16
356	22.71	46.00339	47.0071	51.48602	60.23
357	42.93	58.18285	60.5447	70.18195	72.8
358	25.82	39.52588	41.1425	47.52457	54.97
359	31.18	45.68912	47.0218	50.4946	51.75
360	43.74	52.75426	54.1477	61.51711	63.67
361	33.41	47.42601	47.9616	57.90563	55.73
362	31.29	47.96974	48.7311	61.84202	54.63
363	39.46	52.04994	52.8641	64.25844	56.15
364	40.11	54.27298	53.8631	81.01786	58.47
365	29.55	42.16237	42.3155	50.47906	51.55
366	27.62	42.45036	43.182	58.43322	52.56
367	28.55	42.93974	44.1495	66.22736	50.98
368	31.04	41.76536	43.5201	53.31476	54.78
369	41.64	48.10266	49.3499	64.90321	60.9

370	29.08	38.47	39.7047	57.5196	50.9
371	30.79	44.37807	45.3226	46.18635	58.71
372	25.88	30.34458	31.3989	49.93649	48.99
373	25.03	31.57086	31.6303	59.58872	50.28
374	28.18	45.18051	45.5506	62.05779	53.12
375	41.92	61.78628	62.7167	86.83538	61.11
376	36.83	57.00078	57.3564	84.61286	66.17
377	47.82	45.51587	45.7022	64.54982	65
378	31.4	52.44155	53.6757	69.22195	47.56
379	35.5	55.87191	56.5734	75.72496	47.38
380	43.16	49.58613	49.5646	66.19914	62.63
381	36.57	38.2299	38.3959	53.81539	59.97
382	33.84	41.49595	42.8311	53.45756	53.57
383	27.32	42.49633	43.2577	50.30379	56.28
384	26.06	38.79329	38.7527	53.44219	60.17
385	36.6	44.46207	46.6837	73.63689	51.37
386	47.65	59.87715	60.0024	93.02655	49.41
387	31.67	54.70778	54.7478	75.98526	59.92
388	39.23	42.67489	42.7514	59.96644	55.23
389	30.88	50.93299	50.9317	69.6928	58.65
390	35.45	40.49753	41.2766	69.56275	63.47
391	29.26	64.28963	65.2299	88.41878	69.91
392	34.05	59.62689	60.4637	114.9101	79.59
393	32.95	47.85583	47.0432	74.65475	56.88
394	46.68	54.75825	54.3422	65.10014	64.37
395	45.9	54.50569	55.2081	62.48321	60.38
396	42.96	63.61042	64.7136	85.98263	91.74
397	27.35	52.40287	53.5824	69.37697	67.38
398	35.75	41.81407	41.545	60.92792	69.08
399	27.23	31.24246	31.0382	46.32902	48.44
400	28.22	34.05818	33.4198	39.47421	37.75
401	36.02	44.36525	44.3175	50.39727	54.77
402	33.69	40.76497	41.6588	57.85184	57.86
403	42.62	48.75686	49.2542	57.35411	54.31

404	34.3	42.18664	42.4276	59.38102	52.28
405	41.06	35.08518	35.3506	52.49764	43.32
406	30.58	33.94482	33.6506	35.82669	41.33
407	36.33	42.57884	41.9663	50.38113	43.02
408	55.12	61.66363	60.442	70.9704	67.1
409	23.83	48.61582	48.5005	70.54158	74.32
410	19.39	44.47742	44.5418	67.14134	54.49
411	28.69	34.31721	34.6615	62.62933	54.77
412	35.39	51.45963	50.2839	68.95992	63.36
413	18.69	42.01826	41.0022	63.41282	61.8
414	33.56	54.75987	56.0537	64.57159	59.65
415	39.94	43.95941	43.9119	61.4124	65.6
416	23.9	34.86619	34.3527	49.5354	61.66
417	30.72	35.46868	36.1471	64.42026	51.62
418	34.57	52.70823	52.4093	54.83683	49.73
419	28.54	32.67092	32.9008	52.47618	40.03
420	35.05	30.69321	30.5619	56.7318	50.57
421	24.5	36.08601	36.5836	54.47271	49.91
422	26.39	48.27582	48.6489	62.81387	56.31
423	25.69	43.12743	44.8194	62.1429	59.43
424	26.96	50.30196	50.4322	59.43158	55.85
425	22.09	42.82779	42.7787	48.80183	50.77
426	34.17	38.34595	38.4759	51.31843	56.47
427	35	41.33671	41.2936	43.19873	60.39
428	28.92	33.59349	34.3068	48.26672	59.31
429	42.64	36.87724	36.7751	57.75422	57.76
430	29.54	39.69264	40.7515	60.44558	64.18
431	31.07	35.54548	36.0408	51.96527	63.3
432	26.01	55.17391	54.5239	97.88133	58
433	42.58	60.57012	60.3978	75.65336	57.65
434	34.55	47.37447	47.1704	43.54641	75.81
435	29.32	35.1028	36.0015	50.70066	77.87
436	37.4	39.74254	40.2083	54.31854	77.75
437	41.79	43.24035	44.199	42.67598	60.79

438	35.98	36.54157	35.6574	44.91258	53.95
439	31.77	34.62812	34.2598	45.22284	51.49
440	35.51	42.50655	43.6189	32.89571	54.01
441	25.21	38.21208	39.0871	31.71885	50.05
442	26.58	38.39112	38.527	35.71218	57.53
443	24.89	34.0623	34.2922	39.29901	66.01
444	31.1	41.93479	41.5929	41.21661	77.94
445	28.16	42.52322	42.3653	43.85839	77.2
446	30.89	38.69357	39.258	40.10137	65.43
447	34.15	38.75134	39.9709	44.21079	69.36
448	73.71	70.22804	71.6177	103.4219	95.45
449	50.54	63.50084	64.6745	72.2912	90.68
450	58.73	68.28292	69.9225	69.6607	82.06
451	55.66	77.37266	79.8442	64.41147	111.2
452	51.42	64.7456	65.0587	69.62861	81.35
453	51.85	61.97654	62.8827	74.67201	90.65
454	39.81	53.78822	54.0606	72.71735	82.9
455	49.44	65.21733	64.6474	83.9436	90.95
456	54.03	65.0384	66.3148	91.76114	89.45
457	51.94	69.68974	71.4412	92.68772	100.35
458	36.19	67.50419	67.9793	77.17927	76.17
459	50.02	70.10996	68.8986	73.13771	101.11
460	51.87	66.28033	60.3251	82.30388	89.14
461	54.44	78.7065	74.1768	98.5468	87.51
462	74.83	92.61053	86.5292	111.6342	102.9
463	64.54	104.3577	98.6694	135.0919	109.8
464	58.19	147.4413	135.879	173.7492	138.91
465	62.4	85.63912	88.8403	110.9411	105.39
466	67.44	83.82015	79.9225	78.63869	82.57
467	84.85	84.31653	81.974	74.85547	69.96
468	61.38	83.37371	80.3972	74.49214	66.89
469	80.39	63.93581	76.1934	82.35773	58.47
470	42.47	69.60589	69.6059	78.27359	64.19
471	56.55	59.01761	59.0176	68.69564	59.91

472	41.11	63.30136	64.809	60.30656	58.3
473	43.5	50.80046	50.8278	63.6406	49.45
474	39.27	45.5504	45.5504	75.09837	48.46
475	47.84	55.53635	56.4567	68.76958	49.86
476	53.07	48.23905	46.5243	76.39567	45.87
477	50.3	69.35731	67.0025	63.85721	41.39
478	48.09	56.92065	56.1442	58.74656	31.54
479	46.39	69.02239	69.0224	53.21333	40.25
480	35.99	60.46129	61.4234	49.94381	34.39
481	45.31	40.61181	40.6118	49.22742	42.34
482	31.04	57.08936	54.7531	57.93126	39.97
483	42.45	59.86317	57.9693	65.74289	49.09
484	44.69	59.64591	58.1392	70.00157	50.91
485	52.65	53.95039	51.5093	72.66823	50.59
486	55.31	56.84979	56.8498	82.74415	53.29
487	50.2	52.62878	50.9106	77.36414	59.14
488	49.17	65.47818	63.9257	82.83122	66.02
489	55.22	67.18764	67.8357	78.64846	55.32
490	78.9	94.77731	96.2132	63.23502	28.66
491	66.51	93.89207	94.4551	49.8277	32.18
492	48.22	58.26681	58.2668	52.55348	23.54
493	61.41	55.3492	55.3492	55.97625	38.27
494	51.11	58.81929	58.8193	59.94324	49.92
495	57.22	57.88035	58.9819	53.50279	50.24
496	68.11	72.64122	69.8553	74.95549	53.03
497	47.38	64.69122	59.8369	84.17967	51.22
498	53.44	54.86761	54.8676	84.13047	50.68
499	67.76	76.6685	76.6685	80.85622	54.73
500	75.38	96.53199	96.532	95.37567	35.64
501	55.63	79.70123	80.3782	105.8118	33.37
502	65.62	85.54091	80.8452	92.88	64.37
503	66.95	62.94001	62.94	78.70822	45.36
504	53.61	57.1994	55.7874	68.41977	48.97
505	45.87	52.10287	49.9955	52.58574	52.82

506	50.27	55.42909	53.0681	72.37406	45.3
507	49.99	64.91573	62.1111	73.65059	63.56
508	47.72	77.66699	75.7639	75.48367	47.75
509	55.24	72.35675	71.8945	67.95861	52.45
510	50.45	66.9633	63.602	71.56532	52.22
511	55.51	62.43817	58.1252	66.73271	53.21
512	48.84	66.67857	62.9639	68.66045	47
513	52.53	65.11161	64.472	83.42581	50.4
514	53.29	66.6505	69.0589	69.4636	32.52
515	52.9	58.27521	60.2779	85.88325	35.11
516	59.9	77.8734	77.8734	79.9922	38.92
517	49.38	65.25729	62.7075	63.9881	37.98
518	42.15	66.81379	66.8138	63.69725	31.34
519	46.35	63.587	63.587	46.013	34.55
520	55.34	62.0513	63.4729	55.39551	46.99
521	67.47	63.56061	63.5606	56.26983	43.44
522	66.49	78.76941	78.7694	67.18185	31.24
523	52.07	60.04181	60.0418	55.8334	37.69
524	49	58.49951	58.4995	69.78855	51.33
525	50.46	67.7462	67.7462	48.06833	51.71
526	40.3	60.3775	60.3775	49.92809	38.05
527	54.72	56.58129	56.5813	63.79334	51.24
528	56.39	54.9223	54.9223	57.30942	57.61
529	54.78	65.12909	65.1291	64.68016	47.84
530	75.41	73.75305	70.6206	73.5198	52.68
531	54.24	56.8829	56.8829	51.85046	44.74
532	57.25	66.21061	63.4992	70.9699	54.25
533	37.65	71.9483	71.9483	81.5212	45.22
534	42.76	77.2304	77.2304	67.07046	44.32
535	39.87	63.2866	63.2866	61.08451	41.78
536	32.98	49.2157	49.2157	56.00946	41.65
537	47.54	52.68159	52.6816	67.10399	49.24
538	46.71	57.41599	57.416	77.23224	52.59
539	53.17	60.18671	60.1867	74.83438	57.22

540	49.06	64.66418	65.7105	65.8933	57.23
541	60.48	72.03304	70.501	66.65737	58.09
542	57.9	60.17401	63.0743	62.78587	51.06
543	58.9	56.32748	57.9514	64.14695	37.73
544	41.9	60.62339	60.6234	66.29861	47.64
545	54.24	53.43581	53.6577	59.74113	47.83
546	62.27	79.50773	77.6055	64.30172	57.65
547	58.82	53.36809	53.3681	73.4262	51.51
548	68.94	76.31408	75.9056	71.85285	53.12
549	46.02	63.24671	63.2467	66.44749	41.52
550	52.45	89.75472	89.7547	64.62801	41.89
551	45.95	54.80205	53.4268	73.91905	41.53
552	43.64	64.32184	60.3631	66.53126	41.51
553	56.9	59.2063	55.6961	74.40544	46.93
554	50.47	68.86296	67.1766	65.60208	52.36
555	64.49	70.24823	68.3807	61.48125	47.61
556	56.85	53.51908	53.7424	59.23039	56.03
557	51.06	71.00601	71.006	59.02396	52.51
558	51.83	59.68725	58.9128	50.43594	57.04
559	57.47	54.021	54.021	59.9001	53.15
560	58.28	48.0931	48.0931	70.60284	59.91
561	50.06	46.17671	46.1767	64.75424	48.96
562	43.03	60.5092	60.5092	66.8591	53.24
563	56.14	41.79619	44.089	67.85778	56.4
564	52.55	72.13926	72.9035	72.66896	50.76
565	62.4	64.63549	60.9774	70.68446	49.1
566	57.87	57.38841	57.3884	74.63882	57.71
567	49.09	58.31041	58.3104	67.94782	48.04
568	52.12	69.93853	67.1866	61.36878	31.34
569	50.09	57.6045	57.6045	60.31011	28.16
570	66.28	56.4161	56.4161	72.05309	34.14
571	53.81	64.18849	64.1885	71.58779	37.39
572	60.93	71.22967	68.9458	60.53986	42.64
573	60.01	48.59792	46.4006	67.99821	43.91

574	68.17	66.36065	65.3033	59.35402	50.86
575	37.96	64.7309	64.7309	59.66333	47.5
576	44.8	61.0112	61.0112	64.71086	53.16
577	22.5	62.9021	62.9021	67.86242	56.5
578	16.8	47.47421	47.4742	67.26062	46.53
579	34.39	65.2708	65.2708	73.29557	59.05
580	46.5	64.2463	64.2463	57.8573	49.96
581	60.76	62.4932	62.4932	63.64441	47.71
582	54.45	68.38651	68.3865	79.54319	51.75
583	54.82	52.9214	52.9214	73.74342	51.29
584	58.21	74.86689	74.8669	71.23084	61.9
585	62.02	81.57887	82.0232	74.29422	64.27
586	50.96	83.66411	87.1766	87.01719	62.16
587	62.07	81.74354	80.5848	88.66304	48.21
588	45.99	55.00809	56.0646	53.41293	34.06
589	59.2	75.98266	80.7709	67.24954	52.48
590	53.15	74.61979	78.4078	76.3199	80.32
591	62.87	81.14496	82.7539	87.76263	64.39
592	72.67	97.93172	95.6864	94.7577	73.09
593	53.66	68.95658	69.1104	81.94091	62.36
594	50.95	63.45441	62.8219	69.46248	61.24
595	52.47	66.75326	66.5986	72.93299	63.37
596	58.4	103.5862	103.317	67.40036	64.83
597	54.39	93.71561	93.2534	62.71563	65.61
598	58.69	123.5064	124.332	54.14533	61.7
599	56.03	104.5965	108.586	62.02757	63.13
600	51.12	66.64231	68.1575	64.44445	60.72
601	49.87	52.85694	54.0419	63.73713	95.39
602	44.53	64.19595	62.175	60.01286	225.33
603	61.37	75.55979	75.0038	59.23201	151.52
604	57.9	58.26013	58.7133	57.68951	41.38
605	49.94	64.17974	63.1913	42.13918	40.4
606	51.44	57.33852	61.3331	46.44742	52.68
607	51.8	62.23511	62.3691	49.05374	49.93

608	47.52	55.84521	54.6654	50.70849	52
609	48.76	48.0361	48.4982	55.58306	53.13
610	54.38	49.30939	48.7036	44.16242	51.49
611	60.14	62.40131	59.7336	49.99122	49.11
612	55.13	62.51379	61.362	53.97097	61.67
613	61.31	71.74982	70.4651	68.12728	69.72
614	53.93	80.57767	79.8023	75.84576	66.87
615	54.52	66.71142	67.0733	87.01071	74.2
616	61.43	79.5994	78.4821	67.61823	57.17
617	57.38	62.685	64.3954	63.01252	53.88
618	50.81	76.92819	77.7181	62.3511	49.02
619	62.6	74.07251	73.1953	60.93259	52.53
620	53.6	68.96975	68.8575	63.82234	60.22
621	48.86	57.7489	59.0736	59.64853	55.04
622	50.9	58.88461	60.106	62.50298	64.28
623	49.44	75.10306	74.7223	64.70453	58.3
624	47.55	64.24294	66.2617	59.778	55.03
625	54.1	67.9697	65.6633	62.15178	48.14
626	61.02	71.77478	72.7189	72.74415	63.24
627	70.97	93.94831	96.1661	78.17513	68.04
628	55.05	80.14287	82.4725	91.4121	72.36
629	55.74	60.93444	61.8591	78.48363	73.28
630	53.56	86.38921	89.6552	67.79603	59.27
631	57.39	63.00273	66.5029	68.94554	53.26
632	46.96	74.41883	74.5418	68.28568	53.6
633	64.36	85.41574	82.3328	75.12045	62.8
634	52.91	71.08237	69.6848	62.94569	56.59
635	53.89	77.03019	77.6643	57.73151	54.83
636	47.81	63.44125	61.9352	51.84554	48.22
637	51.5	64.06479	62.6206	59.23755	57.38
638	50	64.46307	63.9888	63.02316	53.09
639	53.58	68.41862	68.7504	65.59639	55.38
640	61.66	70.44079	71.4707	63.69267	61.12
641	55.37	66.43123	67.1262	68.31705	58.79

642	50.71	65.00594	65.9374	66.06061	43.72
643	51.3	65.12505	64.9468	60.32256	53.09
644	52.64	58.5878	57.2278	59.38163	50.74
645	59.12	51.44209	52.7864	54.96487	52.12
646	62.9	60.60909	62.0042	70.72284	65.68
647	64.34	72.05932	70.9543	75.32677	66.32
648	69.97	77.41495	76.9844	75.91929	55.22
649	68.18	71.96635	70.5739	64.10209	65.89
650	59.07	56.48297	54.6857	51.05312	49.98
651	42.43	46.91232	45.7142	54.36575	45.78
652	44.08	50.91131	51.5423	59.31933	56.44
653	56.37	53.13581	53.1435	61.09118	57.76
654	59.4	61.23752	60.717	64.23894	65.04
655	54.62	61.94452	61.1807	53.93935	51.18
656	55.34	59.21344	58.757	67.62331	61.85
657	53.07	53.72138	53.4513	64.93732	55.19
658	51.23	50.30375	49.498	55.92357	57.82
659	52.01	50.32572	49.6549	45.45986	49.2
660	49.28	52.45468	53.9867	54.98991	49.09
661	54.31	53.31249	51.9121	53.87	48.92
662	52.86	50.60033	52.0219	55.62467	54.61
663	62.94	55.44391	55.921	59.92945	53.46
664	63.81	52.17093	52.9321	64.64889	59.18
665	63.44	55.45069	54.8621	62.13411	56.37
666	51.44	62.60425	62.509	60.33463	57.91
667	64.55	67.14567	65.2162	61.17261	56.51
668	56.73	55.28469	54.0191	60.20849	55.91
669	55.02	51.05945	49.9888	56.86634	55.15

Appendix E Widening rate of each station

Station	Widening Rate (Meter per Year)			
	1952 - 1988	1988 - 1992	1992 - 2006	2006 - 2020
0	0.500666	-0.02356	0.516911	0.499316
1	0.39803	0.003399	0.832588	-0.48891
2	0.214137	0.039287	0.453791	-0.26657
3	0.116626	0.042605	0.758773	-0.46824
4	0.162317	-0.01594	1.186958	-0.30566
5	0.145442	-0.04263	-0.41666	0.696066
6	-0.00312	0.070116	0.779139	0.059185
7	0.044239	-0.48872	0.513017	0.027918
8	0.225024	0.303266	0.266	0.282379
9	0.228183	0.182949	0.547136	0.145627
10	0.353903	-0.5955	1.17579	0.072268
11	0.07393	0.306557	0.990852	-0.21351
12	0.190188	0.013633	0.318185	0.083478
13	-0.34892	0.031571	0.025534	-0.44473
14	0.360193	-0.1071	0.181174	-0.69963
15	0.013175	0.020385	0.613478	-0.33336
16	0.054942	0.012365	0.701578	0.021756
17	0.400954	-0.01688	0.42982	-0.15503
18	-0.03834	-0.05874	0.845744	0.176793
19	0.03276	0.089943	0.842559	-0.21128
20	-0.05772	0.076801	0.381875	0.15764
21	0.061281	-0.08576	0.476606	0.240765
22	0.20851	-0.6062	0.434499	0.699973
23	0.11434	-0.02711	0.347168	-0.12631
24	0.569349	-0.01568	0.006869	0.847593
25	0.029578	0.130183	0.679542	0.211418
26	0.158614	-0.02654	0.591619	0.3923
27	0.448477	-0.08244	0.427242	-0.17159
28	0.332756	0.518987	1.05333	-0.17934
29	0.535586	-0.64441	0.18465	-0.62969

30	0.263774	0.037763	0.377146	0.407269
31	0.501012	0.137838	0.577464	-0.18768
32	0.492979	0.087071	0.129764	-0.08025
33	0.248864	0.05724	0.76141	-0.42598
34	0.296024	-0.13672	0.079135	0.240793
35	0.306407	-0.10191	0.989157	0.100382
36	0.588518	-0.0502	0.541161	0.315936
37	0.215904	-0.03588	0.23284	-0.20972
38	0.537148	0.102589	0.65784	0.478088
39	0.473817	-0.05162	0.040599	0.671204
40	0.692888	0.023295	-0.29004	-0.48642
41	0.318039	0.112136	0.922992	-0.55757
42	-0.22398	0.074715	0.141711	-0.02488
43	0.528736	-0.01292	-0.2064	0.15415
44	0.219528	0.057534	0.449873	-0.44954
45	0.224595	0.012085	0.497927	0.160536
46	0.319023	0.316698	-0.08935	0.792904
47	0.156127	0.076345	0.757931	0.113499
48	0.223464	0.152338	0.299708	0.056664
49	0.013892	0.69366	0.743004	-0.33373
50	0.399072	0.105167	0.177516	-0.10659
51	0.439458	-0.04164	-0.90815	1.023673
52	0.123818	-0.00368	0.193539	0.41294
53	0.546672	0.086354	0.405734	-0.15112
54	0.607127	-1.19638	0.99692	-0.02825
55	0.46558	-0.88657	0.888767	-0.25571
56	0.299161	0.143681	0.60596	0.001171
57	0.493462	-0.0709	0.054691	0.3409
58	0.296545	0.219909	0.262967	-0.60247
59	0.113546	0.402489	0.340701	0.012548
60	0.283968	0.034578	-0.37697	0.294486
61	0.432183	-0.09221	0.102067	-0.09717
62	0.382953	0.146147	0.393573	-0.23759
63	0.57657	-0.42099	0.650462	-0.17026

64	0.521269	-0.85188	0.91969	-0.67317
65	0.542249	0.079732	-0.11522	0.135946
66	0.686398	-0.74215	0.721529	-0.36845
67	0.307515	-0.40192	0.704622	-0.28324
68	0.404254	0.151779	0.206716	0.022194
69	0.334522	0.03391	0.445242	-0.69146
70	0.252735	0.002597	0.466827	-0.15249
71	0.463669	0.103441	0.507386	-0.80586
72	0.008944	0.06551	0.521762	-0.29523
73	0.385162	-0.01831	0.007743	-0.20657
74	0.15159	-0.00566	0.571053	-0.31094
75	0.664058	0.161242	-0.81687	-0.40988
76	0.388322	-0.59372	0.094215	-0.54464
77	0.323738	-0.1873	0.154213	-0.00143
78	0.570069	-0.96948	0.469705	-0.61685
79	0.450353	-1.23763	0.18084	0.344643
80	0.368388	-0.52544	-0.25806	0.490639
81	0.282593	-0.42813	0.638598	-0.02239
82	0.663505	0.133409	-0.14968	-0.00244
83	0.180339	-0.02444	0.357586	-0.70165
84	0.451253	0.028511	0.125423	0.322403
85	0.533727	-0.00498	0.749101	-0.51435
86	0.210803	-0.27609	0.640668	-0.1628
87	0.17232	0.07604	0.825429	-0.20446
88	-0.23781	0.073184	1.932124	-0.28423
89	0.387364	-0.75054	0.29021	0.350695
90	0.271678	-1.21596	0.57493	-0.26113
91	0.347762	-0.72016	0.223143	-0.67095
92	0.321064	-0.5346	0.561891	-0.12859
93	0.274703	-0.74986	1.019524	-0.44132
94	0.381894	-0.20081	0.839062	0.213455
95	0.467838	0.046374	0.791226	-0.0021
96	-0.06361	0.029321	0.850309	-0.07552
97	0.36301	-0.0017	0.580727	0.05316

98	0.420271	-0.00049	0.662223	-0.13016
99	0.207015	0.019201	0.899751	-0.444
100	0.20183	0.133899	0.399681	-0.14527
101	0.482096	0.059195	0.17525	-0.11234
102	-0.6221	-0.04897	2.301133	-0.05842
103	0.399229	-0.34127	0.92893	-0.22486
104	0.10867	-0.04326	0.163471	-0.0309
105	0.53086	0.142978	0.664999	0.201773
106	0.119827	0.020144	0.949972	0.374575
107	0.367916	-0.43224	0.767571	-0.48763
108	0.171094	-0.0194	0.524736	-0.52809
109	0.553809	0.107656	-0.31544	-0.32546
110	1.447117	-0.78668	-0.96678	-0.27426
111	1.519675	0.038758	-0.96138	-0.5623
112	0.832368	0.051508	-0.24446	-0.51886
113	0.547108	0.01841	0.18815	-0.07766
114	0.161836	-0.03622	1.611688	-0.54985
115	0.512949	0.054643	0.454243	-0.46944
116	0.49555	0.00324	0.184798	-0.50707
117	0.343852	-0.57864	0.916406	-0.09239
118	0.183809	0.027234	0.432151	0.045988
119	0.073386	-0.68595	0.645151	-0.23494
120	0.201024	-0.78094	0.537539	-0.33512
121	0.55501	-0.52289	0.721011	-0.88119
122	0.226259	-0.04885	0.674222	-0.15757
123	0.385624	-0.21179	0.485957	-0.63364
124	0.225788	-1.27942	0.667684	-0.33235
125	0.212181	-0.36923	0.864548	-0.16107
126	0.502162	0.545625	0.711197	-0.37262
127	0.466627	0.005766	-0.23137	0.025373
128	0.732529	0.071851	-0.53018	-0.42552
129	0.407927	-0.03706	1.05128	-0.20015
130	0.216541	0.04854	0.603139	-0.83281
131	0.552123	0.018775	0.585739	-0.60976

132	0.675995	-0.00628	0.519482	-0.95123
133	0.239297	0.030892	0.559341	-0.4253
134	0.539964	-0.57395	-0.07742	-0.33162
135	0.472455	-0.03899	0.179097	-0.1933
136	0.126314	-0.93286	0.994821	-0.33371
137	0.422376	-0.90546	0.077026	0.163754
138	0.271111	-0.0265	0.796178	-0.16736
139	0.396856	-0.63545	0.510122	-0.02143
140	0.572832	-0.42793	0.548568	-0.62471
141	0.201281	0.436242	1.054651	-0.21107
142	0.26246	-0.76269	0.442882	-0.35729
143	0.095724	0.118321	0.871981	-0.66774
144	0.053801	0.105485	0.842014	-0.57787
145	0.324909	-0.06798	0.813113	-0.30774
146	0.162933	-0.74331	0.386403	-0.04111
147	-0.02081	-0.08512	0.870211	0.166161
148	-0.04166	-0.56922	1.061749	-0.01136
149	0.23983	0.13026	1.254412	-0.9751
150	0.081585	0	0.704576	-0.58901
151	0.309405	-0.35502	0.87925	-0.98982
152	0.162721	0.182624	0.446104	-0.31779
153	0.294705	-0.03754	0.664866	-0.6767
154	0.537119	-0.5818	0.715094	-0.40255
155	0.420256	-0.03032	0.418598	-0.35092
156	0.315265	-0.23944	1.048779	-0.47144
157	0.385319	-0.93514	1.191722	-0.62718
158	0.795561	-0.07418	-0.29662	-0.56122
159	0.481019	-0.13926	0.820447	-0.95404
160	0.233288	0.211323	0.923703	-0.71248
161	-0.26374	0.200972	0.061334	0.797027
162	-0.04733	-0.01377	1.130648	-0.55072
163	0.32702	-0.8971	0.543471	-0.38419
164	0.110768	-0.75538	1.000318	-0.35822
165	0.280112	-1.12205	0.867567	-1.16099

166	0.158344	-0.31063	0.98425	-0.48252
167	0.180609	-0.20175	0.699882	-0.30962
168	0.096421	0.401527	1.210142	-0.46058
169	0.482435	-1.49899	0.390959	-0.07035
170	0.219165	-0.23959	0.664132	-0.58144
171	0.26091	-0.26445	-0.31635	0.392441
172	-0.0147	0	0.533743	-0.24977
173	0.408155	0.404449	-0.23916	-0.20304
174	0.38153	-0.11056	0.040557	0.086034
175	0.037652	0.054162	-0.0317	0.364939
176	0.227538	0	0.799714	-1.00411
177	0.29662	-1.02974	0.55205	-0.22061
178	-0.10489	0	0.800164	-0.70797
179	0.154869	0.073529	0.394675	0.056036
180	0.060298	-0.15321	0.854048	0.330009
181	0.196895	0.164773	0.706977	-1.1502
182	0.27615	-0.53945	1.009391	-0.76016
183	0.481696	0.085321	1.203914	-1.33598
184	0.339336	0.038837	1.155119	-0.92466
185	0.168824	0.065246	0.440251	-0.20586
186	-0.01427	0.301554	1.267188	-0.20502
187	0.002732	0.259809	0.313278	0.711179
188	0.294356	-0.0349	0.893843	-0.42293
189	0.197861	0.026799	-0.07316	0.406721
190	0.085854	0.154691	0.180762	0.012131
191	0.378201	0.014839	0.230254	-0.33487
192	0.569098	0.253972	0.168356	0.088544
193	0.380589	0.076027	0.614856	-0.51738
194	0.292455	0.013583	0.511977	-0.34574
195	0.641177	-0.17734	0.108144	-0.38693
196	0.551138	0.098886	0.309473	-0.79922
197	0.419667	0.144821	0.140813	-0.32991
198	-0.01563	0.12609	0.77694	-0.76778
199	0.127732	-0.14344	0.934596	-1.34635

200	0.067681	0.061921	0.403136	-0.68344
201	0.340242	0.162573	0.613137	-0.75664
202	0.620632	0.010462	0.614451	-0.69478
203	0.259282	0.04976	0.170224	-0.09331
204	0.17119	-0.01556	0.77548	-0.31195
205	0.320747	0.019129	0.129231	-0.04876
206	0.385557	0.076008	0.178456	-0.41232
207	0.301741	-0.00649	0.0372	0.072322
208	0.283629	-0.00153	-0.01857	-0.02247
209	0.067094	0.037351	0.707841	-0.29461
210	0.258879	0.046713	0.288201	-0.13938
211	0.234045	0.021874	0.373887	-0.27482
212	0.511187	0.058146	0.404401	-0.03407
213	0.307107	-0.09314	0.679226	-0.12875
214	-0.15445	0.179716	0.394664	-1.14743
215	-0.37098	0.467988	0.80359	-0.31622
216	-0.01434	0.628582	0.752375	-0.59367
217	0.05652	0.090845	0.544515	-0.82795
218	0.661939	0.110448	0.186194	-0.78917
219	0.236712	-0.02611	0.053282	0.032633
220	-0.1834	0.043991	0.997656	-0.21077
221	-0.8939	-0.07781	1.150238	-0.44511
222	0.083614	0.050196	0.144321	-0.88724
223	-0.36003	-0.02377	0.729391	-0.4368
224	-0.00355	-0.09024	0.885624	0.185012
225	0.192417	-0.01491	0.603315	0.030442
226	0.109906	0.399226	0.730737	0.324727
227	0.243962	0.015218	1.419155	-0.6694
228	0.032277	0.040029	0.781017	-0.51474
229	-0.14407	0.030472	0.600604	-0.23026
230	0.307347	-0.0623	0.976698	-0.80279
231	0.444446	0.151215	-0.13665	-0.0537
232	0.654466	0.25591	-0.07245	-0.17715
233	1.054811	-0.13447	-0.60998	-0.82754

234	0.018567	-0.12792	0.772407	-0.25003
235	0.173053	0.093098	1.309084	-0.29282
236	0.001113	0.040936	1.268122	-0.68482
237	-0.0413	0.0564	1.135078	-0.55428
238	0.21326	0.003206	0.659935	-0.29566
239	-0.0498	0.312922	0.310254	0.118404
240	-0.01002	-0.00427	1.150517	-0.65282
241	0.120938	0.258159	0.409781	-0.45381
242	-0.04449	0.243313	0.613799	0.19038
243	-0.37453	0.259855	0.452705	0.109702
244	0.069102	0.337031	0.678485	-0.23176
245	-0.26748	0.352271	1.54658	-0.93514
246	0.080394	0.131503	0.178094	0.204749
247	0.303317	-0.15715	0.359056	-0.07054
248	0.227787	0.096066	0.733196	-0.70852
249	-0.20611	-0.01402	0.876149	0.139994
250	0.192477	0.041255	0.808108	0.260878
251	0.247355	0.031551	1.431121	-1.00262
252	0.13944	0.192037	0.933256	-0.6774
253	0.387645	0.088566	0.356437	0.004313
254	0.129036	-0.01107	0.947519	-0.29616
255	0.415884	-0.00753	-0.01601	0.216599
256	0.2174	0.045904	0.394065	0.055221
257	0.132106	0.056172	0.195431	0.249534
258	-0.12717	0.318271	0.646963	-0.48376
259	0.241535	-0.03594	0.569097	-0.21135
260	-0.01396	-0.04411	0.39282	-0.09076
261	-0.09386	0.371568	0.257865	-0.02125
262	-0.33562	0.034283	0.621049	-0.21353
263	0.041069	0.006155	0.474069	-0.49786
264	0.284537	-0.01148	0.920081	-0.81704
265	-0.32255	-0.17291	1.192011	0.268246
266	0.077433	0.083875	1.21641	-1.02306
267	0.363489	-0.07186	0.494789	-0.2318

268	0.142946	0.024215	0.07591	0.238883
269	-0.1719	0.099992	0.891609	-0.81102
270	0.047681	-0.1545	-0.003	-0.1319
271	0.646585	0.321457	0.429236	-0.11373
272	0.233368	0.331963	1.155984	-2.15163
273	-0.00366	0.012458	0.717603	-0.45176
274	0.225152	-0.06167	0.297722	-0.12906
275	0.119431	0.230623	0.815608	-0.31147
276	0.239371	-0.14679	-0.25413	0.570545
277	0.093283	-0.09932	0.626383	-1.64216
278	0.232271	-0.02569	0.674937	-0.47415
279	0.483036	-0.01318	0.721919	-0.5981
280	0.546114	-0.0013	0.214375	-0.10615
281	0.160494	-0.18867	0.38393	-0.11701
282	0.153668	-0.09254	0.713075	0.266075
283	0.49536	-0.04081	-0.18974	-0.5431
284	-0.14377	-0.02759	1.786055	-0.93205
285	0.058421	-0.00176	0.407662	0.393331
286	0.2804	0.031424	1.052707	-0.857
287	0.006813	-0.03264	1.545404	-0.55074
288	0.153588	-0.08609	1.063271	-0.24504
289	0.058971	-0.01607	0.429569	-0.5009
290	-0.0462	0.012994	0.691712	-0.80878
291	0.350725	0.2212	-0.34004	0.426407
292	-0.03103	0.305546	-0.18459	0.803514
293	0.362528	-0.03578	1.212155	-0.91058
294	0.336739	0.001427	0.619023	-0.17676
295	-0.04154	0.146609	1.071971	0.020807
296	0.265753	-0.23246	0.959332	-0.36271
297	0.303752	-0.15262	0.537606	-0.48151
298	0.163446	0.130007	0.471581	-0.11545
299	0.176466	0.004827	0.993107	-1.21754
300	0.230643	0.017966	0.401892	-0.01725
301	0.012583	-0.0455	0.345198	-0.27098

302	0.055314	0.222928	0.312981	-0.12891
303	0.249246	-0.11722	-0.06535	0.474346
304	0.521843	-0.13396	0.332635	-0.27338
305	0.248768	0.307187	0.207342	0.330201
306	0.083089	-0.16602	0.723118	-0.24791
307	0.33367	0.22487	1.033521	-0.36935
308	0.348914	0.137598	1.037632	-1.60487
309	0.306297	-0.0118	-0.50478	0.661955
310	0.469246	0.223512	0.156059	-0.31512
311	0.492631	0.329799	0.552088	-0.36665
312	-0.00672	0.325761	0.405328	0.258172
313	0.432393	0.020189	0.283371	0.960421
314	0.337495	0.086468	0.144218	-0.44391
315	0.463367	0.032246	0.387195	-0.65721
316	0.349527	-0.02046	-0.12985	0.046201
317	0.162855	0.128656	0.58631	-0.75827
318	0.876598	-0.05428	-0.35632	-0.57942
319	0.598849	0.33656	0.742789	-0.90813
320	0.188086	0.026276	0.467208	-0.40908
321	-0.28898	0.056918	1.112146	-0.38675
322	0.080199	0.114412	0.439928	0.469015
323	0.20298	0.03613	0.744437	-0.28385
324	0.293194	0.161305	0.751002	-0.53816
325	-0.0786	-0.07914	1.089533	-0.51265
326	-0.31724	0.189748	1.022911	-0.45421
327	-0.23302	0.002692	0.980264	-0.73612
328	-0.22136	-0.06559	0.971773	0.233334
329	-0.15542	0.42144	0.513901	0.169635
330	0.158664	0.082747	1.168358	-0.35714
331	0.065384	0.087467	1.613208	-0.63276
332	0.213193	0.323135	0.39314	-0.74939
333	0.13894	-0.01731	0.665147	-0.0639
334	0.098702	0.003156	0.739913	-0.39105
335	0.053996	0.278259	0.941046	-0.53797

336	0.137065	0.151317	0.983759	-0.24016
337	0.01327	0.11957	0.684842	-0.06813
338	0.058047	0.054853	0.721093	-0.25603
339	0.218744	0.069024	1.253281	-0.22977
340	0.078175	0.229172	0.722441	-0.18894
341	-0.02162	0.225377	1.590197	-0.98256
342	0.231083	0.179805	1.255404	-0.51456
343	0.453443	-0.05912	0.275494	-0.41817
344	0.534939	0.097674	1.127685	-0.16472
345	0.191783	0.26438	9.667096	1.135639
346	0.201715	0.117562	8.769822	-1.87211
347	0.350115	0.046113	0.906907	0.300336
348	0.240316	0.127554	1.805716	0.015598
349	0.164994	0.458026	0.857564	2.050871
350	0.32481	-0.04551	0.955647	0.009274
351	0.210727	0.31336	0.824026	0.053145
352	0.104843	0.244591	1.278034	-0.15894
353	-0.06956	-0.10889	0.571178	0.560951
354	0.23975	0.200777	0.284018	0.828546
355	0.516388	0.240861	-0.2782	0.104384
356	0.647039	0.250927	0.319923	0.62457
357	0.42369	0.590463	0.688375	0.187004
358	0.380719	0.404156	0.455862	0.531817
359	0.403031	0.33317	0.248057	0.089672
360	0.250396	0.348361	0.526386	0.153778
361	0.389334	0.133898	0.710288	-0.1554
362	0.463326	0.19034	0.936494	-0.51514
363	0.349721	0.20354	0.813881	-0.57917
364	0.393416	-0.10247	1.939626	-1.61056
365	0.350344	0.038281	0.583111	0.076496
366	0.411955	0.182909	1.089373	-0.41952
367	0.399715	0.302441	1.57699	-1.0891
368	0.297927	0.438685	0.699618	0.10466
369	0.179518	0.31181	1.110951	-0.28594

370	0.260833	0.308676	1.272493	-0.47283
371	0.377446	0.236134	0.061697	0.894546
372	0.124016	0.263579	1.324114	-0.06761
373	0.18169	0.014861	1.99703	-0.66491
374	0.472236	0.092522	1.179085	-0.63841
375	0.551841	0.232606	1.722763	-1.83753
376	0.5603	0.088904	1.94689	-1.31735
377	-0.064	0.046582	1.346258	0.032156
378	0.584488	0.308537	1.110446	-1.54728
379	0.565886	0.175373	1.367969	-2.02464
380	0.178503	-0.00538	1.188181	-0.25494
381	0.046108	0.041501	1.101392	0.439615
382	0.212665	0.333788	0.759033	0.008031
383	0.421565	0.190343	0.503292	0.426872
384	0.353702	-0.01015	1.049249	0.480558
385	0.218391	0.555408	1.925228	-1.59049
386	0.339643	0.031313	2.358868	-3.11547
387	0.639938	0.010004	1.516961	-1.14752
388	0.095691	0.019127	1.229646	-0.33832
389	0.557028	-0.00032	1.340078	-0.78877
390	0.140209	0.194767	2.020439	-0.4352
391	0.973045	0.235066	1.656349	-1.32206
392	0.710469	0.209202	3.889031	-2.52287
393	0.414051	-0.20316	1.972254	-1.26963
394	0.224396	-0.10401	0.768424	-0.05215
395	0.239047	0.175601	0.519651	-0.15023
396	0.573623	0.275795	1.519216	0.411241
397	0.695913	0.294883	1.128183	-0.14264
398	0.168446	-0.06727	1.384494	0.582291
399	0.111457	-0.05106	1.092201	0.150784
400	0.162172	-0.15959	0.432458	-0.12316
401	0.231812	-0.01194	0.434269	0.312338
402	0.196527	0.223458	1.156645	0.000583
403	0.170468	0.124335	0.578565	-0.21744

404	0.219073	0.06024	1.210958	-0.50722
405	-0.16597	0.066356	1.224788	-0.65555
406	0.093467	-0.07356	0.155435	0.393094
407	0.173579	-0.15314	0.60106	-0.5258
408	0.181767	-0.30541	0.752028	-0.27646
409	0.688495	-0.02883	1.574363	0.269887
410	0.696873	0.016096	1.614253	-0.90367
411	0.156311	0.086073	1.997702	-0.56138
412	0.446379	-0.29393	1.334001	-0.39999
413	0.648007	-0.25401	1.600758	-0.1152
414	0.588885	0.323458	0.608421	-0.35154
415	0.11165	-0.01188	1.250036	0.299114
416	0.304617	-0.12837	1.084478	0.866043
417	0.131908	0.169604	2.019512	-0.9143
418	0.50384	-0.07473	0.173395	-0.36477
419	0.114748	0.057468	1.398241	-0.88901
420	-0.12102	-0.03283	1.869279	-0.44013
421	0.321834	0.124396	1.277794	-0.32591
422	0.607939	0.09327	1.011784	-0.46456
423	0.484373	0.422993	1.237393	-0.19378
424	0.648388	0.03256	0.642813	-0.25583
425	0.57605	-0.01227	0.430224	0.140583
426	0.115999	0.032486	0.917323	0.36797
427	0.17602	-0.01078	0.136081	1.227948
428	0.129819	0.178327	0.997137	0.788806
429	-0.16008	-0.02553	1.498508	0.000413
430	0.282018	0.264714	1.40672	0.266744
431	0.124319	0.123828	1.137462	0.809624
432	0.810109	-0.1625	3.096959	-2.84867
433	0.499726	-0.04308	1.089683	-1.28595
434	0.356235	-0.05102	-0.25886	2.304542
435	0.160633	0.224675	1.04994	1.940667
436	0.065071	0.11644	1.007874	1.673676
437	0.040287	0.239664	-0.10879	1.293859

438	0.015599	-0.22104	0.661085	0.64553
439	0.079392	-0.09208	0.783074	0.447654
440	0.194349	0.278086	-0.76594	1.508164
441	0.361169	0.218756	-0.5263	1.309368
442	0.328087	0.033969	-0.20106	1.558416
443	0.254786	0.057475	0.35763	1.907928
444	0.300966	-0.08547	-0.02688	2.623099
445	0.398978	-0.03948	0.106649	2.381544
446	0.216766	0.141107	0.060241	1.809188
447	0.127815	0.30489	0.302849	1.796372
448	-0.09672	0.347415	2.271732	-0.56942
449	0.360023	0.293415	0.54405	1.313485
450	0.265359	0.409895	-0.0187	0.885664
451	0.603129	0.617885	-1.10234	3.342038
452	0.370155	0.078276	0.326422	0.837242
453	0.281293	0.22654	0.842093	1.141285
454	0.388284	0.068095	1.332625	0.727332
455	0.438259	-0.14248	1.3783	0.500457
456	0.305789	0.319099	1.817596	-0.16508
457	0.493048	0.437864	1.517608	0.547306
458	0.869839	0.118777	0.65714	-0.07209
459	0.558054	-0.30284	0.302794	1.998021
460	0.400287	-1.48881	1.569913	0.488295
461	0.674069	-1.13242	1.740714	-0.78834
462	0.493903	-1.52033	1.793214	-0.62387
463	1.106048	-1.42209	2.60161	-1.80657
464	2.479203	-2.89057	2.705016	-2.48852
465	0.645531	0.800295	1.578632	-0.39651
466	0.455004	-0.97441	-0.0917	0.280808
467	-0.01482	-0.58563	-0.50847	-0.34968
468	0.610936	-0.74413	-0.42179	-0.54301
469	-0.45706	3.064398	0.44031	-1.70627
470	0.753775	2.62E-06	0.61912	-1.00597
471	0.068545	-1.4E-06	0.691288	-0.62755

472	0.616427	0.376909	-0.3216	-0.14333
473	0.20279	0.006836	0.9152	-1.01361
474	0.174456	-2.4E-07	2.110569	-1.90274
475	0.213787	0.230088	0.879492	-1.35068
476	-0.13419	-0.42869	2.133669	-2.18041
477	0.52937	-0.5887	-0.22466	-1.6048
478	0.245296	-0.19411	0.185883	-1.94333
479	0.628678	1.43E-06	-1.12922	-0.92595
480	0.679758	0.240528	-0.81997	-1.11099
481	-0.13051	-1.2E-06	0.615402	-0.49196
482	0.723593	-0.58406	0.227012	-1.28295
483	0.483699	-0.47347	0.555257	-1.18949
484	0.415442	-0.37668	0.847312	-1.36368
485	0.036122	-0.61027	1.511352	-1.57702
486	0.042772	1.67E-06	1.849597	-2.10387
487	0.067466	-0.42954	1.889538	-1.30172
488	0.453005	-0.38812	1.350394	-1.2008
489	0.332434	0.162015	0.77234	-1.66632
490	0.441036	0.358973	-2.35558	-2.46964
491	0.760613	0.140758	-3.18767	-1.26055
492	0.279078	-1.9E-06	-0.40809	-2.07239
493	-0.16836	-7.2E-07	0.044789	-1.26473
494	0.214147	2.15E-06	0.080281	-0.71595
495	0.018343	0.275387	-0.39136	-0.23306
496	0.125867	-0.69648	0.364299	-1.56611
497	0.480867	-1.21358	1.738769	-2.35426
498	0.039656	-1.9E-06	2.090205	-2.38932
499	0.247458	9.54E-07	0.299123	-1.86616
500	0.587555	1.19E-06	-0.08259	-4.26683
501	0.668645	0.169243	1.816685	-5.17441
502	0.553359	-1.17393	0.859629	-2.03643
503	-0.11139	-2.4E-06	1.126302	-2.38202
504	0.099706	-0.353	0.902312	-1.38927
505	0.173135	-0.52684	0.185018	0.016733

506	0.143308	-0.59025	1.378997	-1.93386
507	0.414604	-0.70116	0.82425	-0.72076
508	0.831861	-0.47577	-0.02002	-1.98098
509	0.475465	-0.11556	-0.28114	-1.10776
510	0.458703	-0.84032	0.568808	-1.38181
511	0.192449	-1.07824	0.614822	-0.96591
512	0.495516	-0.92867	0.406896	-1.54718
513	0.349489	-0.1599	1.353843	-2.35899
514	0.371125	0.6021	0.028907	-2.63883
515	0.149311	0.500672	1.828954	-3.62666
516	0.499261	4.77E-07	0.151343	-2.93373
517	0.441036	-0.63745	0.091472	-1.85772
518	0.685105	2.15E-06	-0.22261	-2.31123
519	0.478805	1.43E-06	-1.25529	-0.81879
520	0.186425	0.355401	-0.57696	-0.60039
521	-0.10859	-1.9E-06	-0.52077	-0.91642
522	0.341095	-2.6E-06	-0.82768	-2.56727
523	0.221439	-2.9E-06	-0.3006	-1.29596
524	0.263875	-3.1E-06	0.806361	-1.31847
525	0.480172	-7.2E-07	-1.40556	0.26012
526	0.557708	-7.2E-07	-0.74639	-0.84843
527	0.051703	2.15E-06	0.515146	-0.89667
528	-0.04077	2.38E-07	0.170509	0.02147
529	0.287475	2.62E-06	-0.03207	-1.20287
530	-0.04603	-0.78311	0.207086	-1.48856
531	0.073414	-9.5E-07	-0.35946	-0.50789
532	0.248906	-0.67785	0.533622	-1.19428
533	0.952731	4.77E-07	0.683778	-2.59294
534	0.957511	9.54E-07	-0.72571	-1.62503
535	0.650461	4.77E-07	-0.15729	-1.37889
536	0.450992	-2.4E-07	0.485269	-1.02568
537	0.142822	9.54E-07	1.030171	-1.276
538	0.297389	3.1E-06	1.415445	-1.76016
539	0.194908	-1.7E-06	1.046263	-1.25817

540	0.433449	0.261582	0.013057	-0.61881
541	0.320918	-0.38301	-0.27454	-0.61196
542	0.063167	0.725073	-0.0206	-0.83756
543	-0.07146	0.405981	0.442539	-1.88693
544	0.520094	2.15E-06	0.405372	-1.33276
545	-0.02234	0.055472	0.434531	-0.8508
546	0.478826	-0.47556	-0.95027	-0.47512
547	-0.15144	2.62E-06	1.432722	-1.56544
548	0.204836	-0.10212	-0.28948	-1.33806
549	0.47852	-2.1E-06	0.228628	-1.78054
550	1.036242	-6E-06	-1.79476	-1.62414
551	0.24589	-0.34381	1.463732	-2.3135
552	0.574496	-0.98969	0.440583	-1.78723
553	0.064064	-0.87755	1.336382	-1.96253
554	0.510916	-0.42159	-0.11247	-0.94586
555	0.159951	-0.46688	-0.49282	-0.9908
556	-0.09253	0.05583	0.391999	-0.2286
557	0.554056	-2.6E-06	-0.85586	-0.46528
558	0.218257	-0.19361	-0.60549	0.471718
559	-0.09581	4.77E-07	0.419935	-0.48215
560	-0.28297	1.43E-06	1.607838	-0.76377
561	-0.10787	-2.9E-06	1.326967	-1.12816
562	0.485533	0	0.453564	-0.97279
563	-0.39844	0.573203	1.69777	-0.81841
564	0.544146	0.191061	-0.01675	-1.56493
565	0.062097	-0.91452	0.693362	-1.54175
566	-0.01338	-2.9E-06	1.232173	-1.2092
567	0.256122	-2.6E-06	0.688387	-1.42199
568	0.494959	-0.68798	-0.41556	-2.14491
569	0.208736	-9.5E-07	0.193258	-2.29644
570	-0.274	2.38E-07	1.116928	-2.70808
571	0.288292	1.19E-06	0.52852	-2.4427
572	0.286102	-0.57097	-0.60042	-1.27856
573	-0.317	-0.54933	1.542687	-1.72059

574	-0.05026	-0.26434	-0.42495	-0.60672
575	0.743636	4.77E-07	-0.36197	-0.86881
576	0.450311	1.19E-06	0.264261	-0.82506
577	1.12228	4.77E-07	0.354308	-0.8116
578	0.852061	-2.4E-06	1.413316	-1.48076
579	0.8578	0	0.573198	-1.01754
580	0.492953	7.15E-07	-0.45636	-0.56409
581	0.048144	7.15E-07	0.082229	-1.13817
582	0.387125	-2.4E-06	0.796906	-1.98523
583	-0.05274	-4.8E-07	1.487287	-1.60382
584	0.462692	7.15E-07	-0.25972	-0.66649
585	0.543302	0.111084	-0.55207	-0.71602
586	0.908447	0.878123	-0.01139	-1.77551
587	0.546487	-0.28969	0.577017	-2.8895
588	0.250503	0.264127	-0.18941	-1.38235
589	0.466185	1.197059	-0.96581	-1.05497
590	0.596383	0.947001	-0.14914	0.285722
591	0.507638	0.402235	0.357767	-1.66947
592	0.701714	-0.56133	-0.06634	-1.54769
593	0.424905	0.038454	0.916466	-1.39864
594	0.347345	-0.15813	0.474327	-0.58732
595	0.396757	-0.03866	0.452456	-0.68307
596	1.255172	-0.0673	-2.56547	-0.1836
597	1.092378	-0.11555	-2.18127	0.206741
598	1.800457	0.206391	-5.01333	0.539619
599	1.349069	0.997379	-3.3256	0.078745
600	0.431175	0.378797	-0.26522	-0.26603
601	0.082971	0.29624	0.692517	2.260919
602	0.546276	-0.50524	-0.15444	11.80837
603	0.394161	-0.139	-1.12656	6.591999
604	0.010004	0.113292	-0.07313	-1.16496
605	0.395548	-0.24711	-1.50372	-0.12423
606	0.163848	0.998646	-1.06326	0.445185
607	0.289864	0.033497	-0.9511	0.06259

608	0.231256	-0.29495	-0.28264	0.092251
609	-0.02011	0.115526	0.506062	-0.17522
610	-0.14085	-0.15145	-0.32437	0.523398
611	0.062814	-0.66693	-0.69588	-0.06294
612	0.205105	-0.28795	-0.52793	0.549931
613	0.289995	-0.32118	-0.16699	0.113765
614	0.740213	-0.19384	-0.28261	-0.64113
615	0.33865	0.090472	1.4241	-0.91505
616	0.504706	-0.27932	-0.77599	-0.7463
617	0.147361	0.4276	-0.09878	-0.65232
618	0.725505	0.197479	-1.09764	-0.95222
619	0.318681	-0.2193	-0.87591	-0.60019
620	0.426937	-0.02806	-0.35965	-0.25731
621	0.246914	0.331175	0.041066	-0.32918
622	0.221795	0.305346	0.171213	0.12693
623	0.712863	-0.09519	-0.71556	-0.45747
624	0.463693	0.50469	-0.46312	-0.33914
625	0.385269	-0.5766	-0.25082	-1.00084
626	0.298744	0.236031	0.001803	-0.67887
627	0.638286	0.554448	-1.28507	-0.72394
628	0.697024	0.582408	0.638543	-1.36086
629	0.14429	0.231164	1.187466	-0.37169
630	0.911922	0.816497	-1.56137	-0.609
631	0.155909	0.875041	0.174475	-1.1204
632	0.762745	0.030743	-0.44687	-1.04898
633	0.584882	-0.77073	-0.51517	-0.88003
634	0.504788	-0.34939	-0.48137	-0.45398
635	0.642783	0.158528	-1.42377	-0.20725
636	0.434201	-0.37651	-0.72069	-0.25897
637	0.349022	-0.36105	-0.24165	-0.13268
638	0.401752	-0.11857	-0.06897	-0.70951
639	0.412184	0.082944	-0.22529	-0.72974
640	0.243911	0.257478	-0.55557	-0.18376
641	0.307256	0.173741	0.085061	-0.6805

642	0.397109	0.232865	0.008801	-1.59576
643	0.384029	-0.04456	-0.3303	-0.51661
644	0.165217	-0.34	0.153845	-0.61726
645	-0.21328	0.336077	0.155605	-0.20321
646	-0.06364	0.348778	0.62276	-0.3602
647	0.214426	-0.27626	0.312319	-0.64334
648	0.206804	-0.10764	-0.07608	-1.47852
649	0.105177	-0.34811	-0.46227	0.127708
650	-0.07186	-0.44932	-0.25947	-0.07665
651	0.124509	-0.29953	0.617968	-0.61327
652	0.189759	0.157747	0.555502	-0.20567
653	-0.08984	0.001922	0.567691	-0.23794
654	0.051042	-0.13013	0.251567	0.057219
655	0.203459	-0.19096	-0.51724	-0.1971
656	0.107596	-0.11411	0.633308	-0.41238
657	0.018094	-0.06752	0.82043	-0.69624
658	-0.02573	-0.20144	0.458969	0.135459
659	-0.04679	-0.16771	-0.29965	0.267153
660	0.088186	0.383004	0.071658	-0.42142
661	-0.02771	-0.3501	0.13985	-0.35357
662	-0.06277	0.355391	0.257341	-0.07248
663	-0.20822	0.119273	0.286318	-0.4621
664	-0.32331	0.190291	0.836914	-0.39064
665	-0.22193	-0.14715	0.51943	-0.41172
666	0.310118	-0.02381	-0.15531	-0.17319
667	0.072102	-0.48237	-0.28883	-0.33304
668	-0.04015	-0.3164	0.442099	-0.30703
669	-0.11002	-0.26766	0.491253	-0.1226

Appendix F Migration rate of each station

Station	Migration Rate (Meter per Year)			
	1952 - 1988	1988 - 1992	1992 - 2006	2006 - 2020
0	0.303885	0.062986	0.89145	1.221657
1	0.226336	0.179688	1.310161	0.96018
2	0.131556	0.042969	1.37684	0.89549
3	0.090778	0.190247	1.229415	1.247351
4	0.090446	0.121094	1.368812	1.476241
5	0.00626	0.082031	0.631345	0.951632
6	0.75376	0.271337	1.136422	0.257251
7	0.501409	1.179513	1.576803	0.648683
8	0.498466	0.662913	1.229103	0.363147
9	0.008427	0.226461	0.90531	0.656857
10	0.919953	1.1495	0.989638	0.424371
11	1.016118	0.724207	0.957319	0.43604
12	0.899287	0.103128	0.151724	0.765343
13	0.793602	0.15625	0.662162	0.606881
14	0.856473	0.080529	0.347012	0.590519
15	0.621993	0.145373	0.076163	0.371746
16	0.490678	0.234375	0.026127	0.675813
17	0.505196	0.100125	0.1855	0.652534
18	0.946185	0.059626	0.499941	0.685192
19	1.020878	0.326353	0.340926	0.935255
20	1.174551	0.235187	0.985447	1.074496
21	0.840601	0.085671	0.796296	0.157303
22	0.236432	1.754185	0.413352	0.458336
23	1.30632	0.125061	0.490142	0.374842
24	0.912987	0.128847	0.25698	0.126269
25	0.951855	0.163177	0.25476	0.310781
26	0.474087	0.091443	0.18361	0.276389
27	0.73613	0.147406	0.939014	0.281252
28	0.90824	1.38456	1.231498	0.0742

29	0.695922	1.297587	0.836521	0.606765
30	0.153332	0.065481	0.553762	0.040441
31	0.674523	0.162568	1.024126	0.17796
32	0.421789	0.165774	0.063929	0.018973
33	0.251084	0.303207	0.810514	0.257368
34	0.282191	0.178324	0.483176	0.176667
35	0.579955	0.036851	0.371482	0.139687
36	0.365277	0.197642	0.427879	0.0864
37	0.796141	0.080529	1.431806	0.285158
38	0.515521	0.337862	1.387641	0.491766
39	1.642846	0.084143	1.742213	0.041159
40	1.796806	0.066406	0.834106	0.795357
41	1.575004	0.359905	0.427071	1.067194
42	0.326507	0.317249	0.715527	0.522552
43	0.740243	0.062986	0.406521	0.287957
44	0.755972	0.089844	0.21223	0.522971
45	1.014801	0.076944	0.406509	0.184692
46	0.891083	0.870524	0.470474	0.246712
47	1.235129	0.095043	0.91165	0.326506
48	1.295702	0.140245	0.621114	0.883941
49	1.232858	1.500834	1.229327	0.570421
50	0.560133	0.254357	0.412833	0.454833
51	0.612752	0.193271	0.504464	0.506067
52	0.167804	0.032212	0.412077	0.318258
53	0.15731	0.375081	0.671608	0.259889
54	0.11258	2.500403	0.764423	0.097015
55	0.278996	1.89908	0.21762	0.514154
56	0.637406	0.272879	0.355023	0.580567
57	0.670791	0.09375	0.44118	0.461206
58	0.755039	0.430822	0.063135	0.790421
59	0.849784	0.81013	0.162946	0.65666
60	1.205546	0.179688	0.589662	0.850151
61	0.932817	0.395593	0.04334	0.845767
62	1.371929	0.164063	0.817297	0.581386

63	1.078062	0.902504	0.611562	0.781033
64	1.046333	2.578752	0.359652	0.792587
65	1.222741	0.174693	0.245018	0.738499
66	1.048519	1.834341	0.321622	0.71586
67	1.456291	0.829782	0.32964	0.769209
68	1.053785	0.056337	0.333666	0.606223
69	1.321207	0.084143	0.228258	0.512407
70	1.304859	0.023438	0.0325	0.660658
71	1.568224	0.032212	0.708121	0.598385
72	1.904102	0.088388	1.267889	0.571498
73	1.605669	0.069877	0.205551	0.511473
74	1.69078	0.146784	0.544716	0.551628
75	1.889847	0.265625	0.978995	0.353278
76	1.645757	0.399661	0.13877	0.347017
77	1.567802	0.515388	0.427833	0.662883
78	2.446833	2.070593	1.485098	0.541565
79	2.464596	2.531262	1.60532	1.161266
80	2.354186	1.039532	1.534755	1.00733
81	1.941978	0.867188	0.717018	0.553859
82	1.421045	0.076944	0.024554	0.707646
83	1.619355	0.044194	0.160962	0.397603
84	1.967299	0.146784	0.763171	0.609502
85	0.256606	0.015625	0.0834	0.16073
86	0.032212	2.602313	0.634592	0.286767
87	0.076433	0.034939	0.251431	0.019965
88	0.168966	0.007813	0.028235	0.117437
89	0.83066	1.421188	0.732826	0.121442
90	1.295756	0.907941	0.765427	0.108827
91	2.459055	2.163883	1.536224	0.400583
92	2.481156	3.683776	0.841599	0.769053
93	2.033682	0.536793	0.938562	0.758538
94	0.982082	0.31986	0.451754	0.150703
95	0.070158	0.108535	0.499222	0.519629
96	0.493698	0.083048	0.618799	0.0625

97	0.157068	0.127178	0.910539	0.035714
98	0.011117	0.117188	0.091054	0.063174
99	0.472306	0.419263	0.139754	0.220519
100	1.134987	2.270953	1.006637	0.117628
101	0.575552	0.787514	1.35229	0.139469
102	1.173962	0.046875	1.441876	0.217528
103	0.440173	1.569049	1.007238	0.793918
104	1.047743	0.226563	0.969339	0.449903
105	1.476659	0.209631	1.463006	0.749099
106	1.245004	0.132583	1.12554	0.710877
107	1.267963	0.843786	0.952359	0.459388
108	0.893752	0.007813	0.950046	0.541119
109	0.52237	0.104816	0.035992	0.14459
110	0.913942	1.675904	1.368245	0.13109
111	0.689112	0.091443	1.247063	0.104124
112	0.723106	0.175564	0.503891	0.236607
113	0.639464	0.161059	0.255831	0.402405
114	0.594451	0.056337	0.006696	0.455729
115	0.676839	0.091443	0.153759	1.060869
116	0.809894	0.050024	0.463647	0.529282
117	0.697922	1.361439	0.341226	0.476927
118	0.75324	0.101563	0.225004	0.425872
119	0.693002	1.6253	0.262027	0.618847
120	0.69198	1.481988	0.524173	0.694652
121	0.602658	0.351128	0.643616	0.608192
122	0.368416	0.03125	0.110823	0.739348
123	0.570635	0.482165	0.102993	0.547713
124	0.255202	2.381275	0.378623	0.619829
125	0.483706	0.632764	0.386309	0.975079
126	0.23223	1.152125	0.150484	0.571642
127	0.094873	0.054688	0.871268	0.62602
128	0.159195	1.066628	1.852437	0.405593
129	0.267722	0.078125	1.100211	0.860542
130	0.441779	0.039063	0.405348	0.397303

131	0.316682	0.06675	0.419857	0.658089
132	0.383193	0.023438	0.166575	0.57077
133	0.145139	0.096635	0.542829	0.657873
134	0.019507	0.922405	0.578724	0.763341
135	0.00626	0.06675	0.73703	0.87441
136	0.017705	0.635891	0.62062	0.730784
137	0.190136	1.789335	0.941964	0.435359
138	0.040493	0.056337	1.063213	0.619077
139	0.146742	1.314359	0.764163	0.409554
140	0.371358	0.740994	0.888631	0.26834
141	0.323052	0.983382	0.687388	0.128324
142	0.077956	1.63257	0.959481	0.185483
143	0.24318	0.069877	0.347756	0.387243
144	0.008549	0.190247	0.987266	0.545155
145	0.027994	0.164063	1.048359	1.111204
146	0.375823	1.64384	0.51995	1.032267
147	0.508483	0.083048	0.048082	0.534019
148	0.463382	1.023646	0.669166	0.380513
149	0.165853	0.335938	1.211073	1.041493
150	0.08674	0	0.206916	0.921291
151	0.367966	1.367188	0.109807	0.305404
152	0.534722	0.157998	0.76786	0.062659
153	0.688035	0.101563	0.464463	0.128324
154	2.183686	0.69285	0.407328	0.868691
155	0.586195	0.136439	0.015625	0.375106
156	0.346206	0.985367	0.539422	0.515388
157	0.534553	0.034939	0.506986	0.456936
158	0.23014	0.132813	0.843221	0.665718
159	0.228251	0.112673	0.277729	0.42617
160	0.384306	0.31289	0.300743	0.20682
161	0.72661	0.722181	0.357254	0.080481
162	0.128847	0.062986	0.474019	0.532879
163	0.174617	1.787014	0.793466	0.470093
164	0.272807	1.6253	1.064383	0.353553

165	0.007417	2.21171	1.107811	0.332192
166	0.206473	1.549319	0.126032	0.519284
167	0.130993	0.232282	0.037946	0.362797
168	0.464234	0.783746	0.540755	0.574836
169	0.142385	1.718768	0.571782	0.518549
170	0.18324	0.647307	0.262749	0.542222
171	0.902077	0.676221	0.101801	0.143761
172	0.696828	0	0.807385	0.076286
173	0.466928	0.815237	0.780063	0.667948
174	0.50224	3.395913	0.89842	0.663217
175	0.552308	0.03125	0.712138	0.382081
176	0.592215	0	1.206731	0.675219
177	0.340667	1.855777	0.036337	0.118871
178	0.375138	0	0.209405	0.385334
179	0.076092	0.349386	0.467899	0.100322
180	0.377599	0.372469	0.026127	0.966598
181	0.301969	0.32961	0.859375	0.96912
182	0.331997	1.258783	0.367077	0.019965
183	0.052437	0.100049	0.251431	0.137526
184	0.059034	0.272879	1.186694	0.805606
185	0.332166	0.054688	0.778301	0.572004
186	0.445021	0.378967	1.153793	0.242103
187	0.344408	0.489701	0.74579	0.47033
188	0.20848	0.159344	0.492171	0.21598
189	0.049904	0.062986	0.111607	0.083558
190	0.03844	0.248162	0.042116	0.054676
191	0.019038	0.190086	0.03036	0.00325
192	0.007158	0.469791	0.151851	0.277063
193	0.06945	0.03125	0.178697	0.4313
194	0.097412	0.032212	0.259544	0.019451
195	0.032012	0.46901	0.215445	0.15586
196	0.14951	0.062986	0.366507	0.068573
197	0.003579	0.157998	0.05431	0.143315
198	0.065237	0.191526	0.221343	0.576272

199	0.219218	0.283089	0.48285	0.499359
200	0.037558	0.278195	0.175929	0.132454
201	0.010737	0.288111	0.05893	0.33046
202	0.113646	0.064424	0.27693	0.27761
203	0.03294	0.062986	0.06715	0.023354
204	0.110079	0.336573	0.187088	0.622507
205	0.124471	0.078125	0.340524	0.218775
206	0.233817	0.015625	0.601706	0.019655
207	0.006998	0.095043	0.026879	0.204232
208	0.061289	0.032212	0.14967	0.05078
209	0.01098	0.095043	0.004464	0.105158
210	0.146205	0.098821	0.40337	0.314875
211	0.257419	0.015625	0.661679	0.219575
212	0.573085	0.06675	1.455646	0.107044
213	0.274428	0.101563	0.68121	0.110351
214	0.234085	0.587134	0.768687	0.281416
215	0.421922	0.712652	1.288501	0.328278
216	0.862008	0.682197	2.409624	0.756616
217	0.591471	0.314932	1.60914	0.566558
218	0.099433	0.076944	0.234067	0.735479
219	0.247822	0.083048	0.660956	0.439309
220	0.165179	0.046875	0.432143	0.403817
221	0.096791	0.956098	0.060721	0.55125
222	0.224384	0.083048	0.59903	0.845242
223	0.104297	0.06675	0.285793	0.163768
224	0.03155	0.282981	0.020089	0.031652
225	0.236882	0.151691	0.598252	0.064085
226	0.215285	0.339552	0.466219	0.12641
227	0.07735	0.190247	0.196745	0.161496
228	0.277995	0.286518	0.796675	0.487922
229	0.348716	0.138217	0.879161	0.768551
230	0.318718	0.234375	0.756591	0.570257
231	0.369482	0.182217	0.899362	0.207684
232	0.309851	0.212523	0.742791	0.017009

233	0.141536	0.267457	0.435588	0.814405
234	0.153115	0.249144	0.464908	0.785306
235	0.180631	0.318018	0.387963	0.258235
236	0.083735	0.138217	0.234874	0.228151
237	0.165259	0.386857	0.50008	0.118611
238	0.095915	0.363176	0.349956	0.18784
239	0.11641	0.150073	0.286559	0.384826
240	0.20548	0.331548	0.465058	0.058137
241	0.063742	0.171342	0.15633	0.087276
242	0.417548	0.450694	0.945459	0.653933
243	0.477782	1.437585	0.817857	0.628556
244	0.21886	0.235025	0.50764	0.365336
245	0.175819	0.268823	0.384862	0.12224
246	0.094151	0.375	0.348929	0.235876
247	0.359464	0.100049	0.899531	0.339623
248	0.067245	0.618126	0.015625	0.113253
249	0.270946	0.096635	0.72371	0.198177
250	0.128569	0.254357	0.398705	0.43969
251	0.211207	0.125973	0.509496	0.820828
252	0.006998	0.098821	0.011161	0.372412
253	0.03541	0.501524	0.233949	0.037736
254	0.00491	0.544022	0.144952	0.272377
255	0.063842	0.0625	0.161472	0.462433
256	0.257788	0.056337	0.670847	0.092509
257	0.197919	0.174693	0.553936	0.654091
258	0.291472	0.399661	0.642919	0.624932
259	0.044812	0.218889	0.054494	0.081326
260	0.025054	0.282225	0.143136	0.134364
261	0.41015	1.435992	0.646628	0.562411
262	0.072049	0.09375	0.212054	0.778885
263	0.177389	0.151691	0.498088	0.549688
264	0.087639	0.1875	0.174522	1.050501
265	0.199587	0.279508	0.434122	0.257574
266	0.069444	0.03125	0.184067	0.696472

267	0.03937	0.251946	0.172915	0.32833
268	0.015528	0.098821	0.063135	0.014879
269	0.137057	0.536964	0.5035	0.424542
270	0.125796	0.254357	0.394988	0.171699
271	0.079937	0.346931	0.10649	0.538051
272	0.500663	0.537248	1.134008	0.134792
273	0.048681	0.28395	0.050508	0.025238
274	0.063225	0.015625	0.163313	0.141319
275	0.019814	0.191526	0.016096	0.2579
276	0.350733	0.095043	0.928743	0.942578
277	0.336493	0.392262	0.973102	0.240463
278	0.226734	0.24407	0.519471	0.259025
279	0.546189	0.166096	1.367211	0.297681
280	0.264169	0.148438	0.682558	0.386605
281	0.166992	0.285129	0.348472	0.369127
282	0.080092	0.312598	0.117437	0.694751
283	0.028895	0.203125	0.019965	0.473952
284	0.031298	0.083048	0.060926	0.288549
285	0.115347	0.25243	0.226944	0.31822
286	0.034895	0.232282	0.154969	0.642938
287	0.027994	0.125	0.044643	0.013426
288	0.272355	0.293255	0.61788	0.030399
289	0.233778	0.0625	0.617884	0.204904
290	0.351005	0.150073	0.862936	0.631895
291	0.153132	0.056337	0.386025	0.57865
292	0.084483	0.125973	0.251946	0.873067
293	0.212551	0.151691	0.525692	0.350809
294	0.393378	0.21324	0.954984	0.010932
295	0.405791	0.151691	1.084812	0.149832
296	0.070398	0.306286	0.268452	0.254939
297	0.098794	0.317249	0.163481	0.485656
298	0.192264	0.235025	0.428129	0.659364
299	0.089271	0.279508	0.307874	0.166193
300	0.346753	0.455007	0.769775	0.728613

301	0.281755	0.21324	0.690508	0.536063
302	0.37397	0.377029	0.854048	1.063825
303	0.176947	0.18815	0.507851	0.512397
304	0.102948	0.457749	0.134003	0.840181
305	0.056902	0.288217	0.227635	0.135007
306	0.168718	0.573674	0.269942	0.511584
307	0.29677	1.09375	0.451053	0.200895
308	0.059996	0.251946	0.226241	0.070805
309	0.386104	0.161059	0.95233	0.606409
310	0.085797	0.147406	0.178697	0.354492
311	0.32065	0.568759	0.986971	0.415135
312	0.461264	0.477586	1.049715	0.343408
313	0.381	0.125973	1.013973	0.217743
314	0.243483	0.219307	0.688427	0.314285
315	0.795533	0.094075	2.019205	0.649839
316	0.507664	0.044194	1.305315	0.763098
317	0.525652	0.125973	1.354468	0.916914
318	0.442372	0.3763	1.243961	0.745895
319	0.397842	0.844329	0.782423	0.037709
320	0.047227	0.461996	0.011161	0.096718
321	0.445786	0.175564	1.195829	0.661256
322	0.017895	0.039063	0.056469	0.059387
323	0.187438	0.06675	0.46319	0.780104
324	0.362171	0.088388	0.906088	0.585899
325	0.132381	0.136439	0.301496	0.279342
326	0.180658	0.375081	0.571585	0.544726
327	0.11519	0.514025	0.152833	0.077298
328	0.247266	0.412512	0.753447	0.339998
329	0.360243	0.128847	0.962095	0.997771
330	0.463408	0.100049	1.219861	1.023264
331	0.420272	0.853531	1.324539	0.806328
332	0.024552	0.659219	0.127838	0.39415
333	0.447588	0.338111	1.054517	1.164623
334	0.459138	0.153888	1.137614	0.687429

335	0.420024	0.669554	1.271297	1.100529
336	0.392042	0.602374	1.179807	1.162299
337	0.279336	0.151691	0.759011	0.640268
338	0.4039	0.050024	1.041624	1.063336
339	0.300106	0.737526	0.982396	1.283369
340	0.135695	0.438127	0.473472	1.022822
341	0.225755	0.420716	0.464629	0.181961
342	0.471309	0.194058	1.26604	1.195017
343	0.542114	0.032212	1.397059	1.591881
344	0.23764	0.064424	0.595648	0.778704
345	1.845378	0.3271	4.651821	1.111832
346	1.287542	0.654201	3.497631	4.121463
347	0.807881	0.062986	2.088791	1.236997
348	0.011117	0.032212	0.036337	3.067233
349	0.220098	0.786894	0.787905	0.655358
350	0.809903	0.023438	2.089305	0.990373
351	0.064866	0.929129	0.099824	0.485984
352	0.074572	1.178238	0.528377	0.242683
353	0.099675	0.261923	0.331088	0.378238
354	0.017705	0.096635	0.017996	0.519481
355	0.359204	0.044194	0.936162	0.293819
356	0.563464	0.914597	1.709915	0.578644
357	0.699661	0.532168	1.647321	0.290121
358	0.027683	0.088388	0.096397	0.014661
359	0.114666	0.159344	0.25001	0.188438
360	0.024367	0.46875	0.071568	0.057785
361	0.466669	0.307876	1.284287	0.703583
362	0.468029	0.902234	1.46054	0.746157
363	0.889474	0.877821	2.537978	0.755312
364	0.642448	0.039063	1.658398	0.821643
365	0.34509	0.127178	0.923546	0.036739
366	0.156445	0.472898	0.537057	0.542612
367	0.153024	0.46901	0.527088	0.639763
368	0.021281	0.377918	0.162579	0.244203

369	0.222712	0.352516	0.672349	0.93628
370	0.159958	0.68821	0.607947	0.300362
371	0.073575	0.574577	0.352601	0.707314
372	0.2469	0.157029	0.67816	0.340487
373	0.32545	0.604801	0.664508	0.587737
374	0.275961	0.096635	0.725374	1.061213
375	0.13199	0.311326	0.425608	0.56612
376	0.775555	0.337388	1.898665	0.617841
377	0.920139	0.205069	2.312139	0.158005
378	0.834407	0.320598	2.23573	1.964152
379	0.541984	0.433295	1.269979	1.898627
380	0.247457	0.056337	0.651055	0.290419
381	0.410663	0.182217	1.009916	0.81143
382	0.472927	0.372469	1.109734	0.969244
383	0.31462	0.164063	0.764948	0.333512
384	0.278801	0.963823	0.992197	0.277736
385	0.652848	1.012164	1.96794	1.000983
386	0.977315	0.139754	2.473223	2.558032
387	0.593156	0.091443	1.499495	2.083002
388	0.418417	0.108535	1.091664	0.462971
389	0.197278	0.195313	0.467217	0.36386
390	0.039589	0.449134	0.055804	0.690155
391	0.197263	0.254357	0.579055	0.638655
392	1.030768	0.098821	2.622312	2.095885
393	0.807294	0.862671	2.32157	1.801271
394	0.427987	0.362503	1.204075	0.80808
395	0.158443	0.779412	0.628629	0.404917
396	0.352983	0.71261	1.110291	0.517354
397	0.03155	0.276103	0.153418	0.256229
398	0.172435	0.262505	0.374475	0.388708
399	0.23959	0.056337	0.604313	0.503197
400	0.062795	0.250122	0.232529	0.642237
401	0.145264	0.069877	0.386335	0.049516
402	0.064872	0.390625	0.277729	0.28298

403	0.139865	0.601106	0.527017	0.123055
404	0.251203	0.094075	0.624334	0.544008
405	0.107558	0.391561	0.388322	0.589646
406	0.050861	0.821799	0.104124	0.62431
407	0.086806	0.35844	0.322736	0.109315
408	0.182814	0.076944	0.476237	0.367387
409	0.027994	0.278195	0.145962	0.123405
410	0.446259	0.03125	1.153914	0.332024
411	0.080804	0.182217	0.156457	0.581891
412	0.024445	0.635507	0.242883	0.478538
413	0.436262	0.634498	0.941022	0.013077
414	0.2527	0.341702	0.745268	0.3062
415	0.309234	0.360477	0.693044	0.136943
416	0.236814	0.471088	0.743518	1.117722
417	0.345918	0.122035	0.876877	1.117794
418	0.413895	0.573035	1.226162	1.375803
419	0.392132	0.223716	1.072193	0.914291
420	0.488637	0.139754	1.21731	0.802995
421	0.290768	0.117188	0.719415	1.077183
422	0.724422	0.127178	1.87448	1.416334
423	0.199887	0.580653	0.349728	0.613078
424	0.367352	1.202212	1.287823	0.198329
425	0.822677	0.083048	2.133005	1.185336
426	0.89991	0.940101	2.581905	1.338108
427	0.780451	0.853853	2.250443	1.275798
428	0.598181	0.245193	1.605083	0.48565
429	0.170148	0.098821	0.417285	0.461003
430	0.195282	0.225482	0.566542	0.541763
431	0.073247	0.127178	0.152195	0.253601
432	0.128578	0.096635	0.310461	1.003748
433	0.133333	0.166096	0.296606	1.51317
434	0.642961	0.232282	1.592048	0.682776
435	0.258944	0.343839	0.569542	0.602062
436	0.216116	0.767735	0.772002	0.08936

437	0.325835	0.492683	0.699128	0.04655
438	0.337739	0.281684	0.790569	0.166297
439	0.644848	0.084143	1.656618	0.531864
440	0.601753	0.248162	1.618265	0.713156
441	0.447251	0.301769	1.235247	0.885044
442	0.207173	0.294812	0.453603	0.299326
443	0.244638	0.197642	0.68442	0.393388
444	0.195557	0.40331	0.393016	0.566085
445	0.278007	0.091443	0.705371	0.356527
446	0.153722	0.722983	0.598764	0.720853
447	0.195297	0.336573	0.589391	1.217158
448	0.298616	0.234375	0.715178	0.487242
449	0.470099	0.122035	1.184057	1.056455
450	0.426009	0.156445	1.140083	0.805076
451	0.483388	0.312598	1.153998	1.419547
452	0.461826	0.920981	0.929258	0.811552
453	0.438327	0.06675	1.144565	1.464746
454	0.174658	3.512568	0.554722	1.65383
455	0.027791	0.613965	0.245586	0.751508
456	0.358229	0.844365	0.680741	0.856179
457	0.043403	0.822059	0.125715	0.591306
458	0.045272	0.42648	0.009982	0.023126
459	0.017361	1.395466	0.442983	0.366555
460	0.277974	2.760644	1.500239	0.704712
461	0.482704	1.609375	1.699809	0.887745
462	0.995634	1.320313	2.187966	1.814607
463	1.260163	3.093592	2.360455	1.170158
464	1.826006	10.88043	1.600009	0.212115
465	5.543873	42.62425	2.080502	1.42978
466	8.745482	74.22622	1.282711	0.615847
467	10.78838	92.01017	1.453674	1.153417
468	9.363094	79.78713	1.285809	1.203033
469	1.591475	10.65709	1.053694	1.31917
470	0.158322	0.906284	0.534243	1.634372

471	0.462165	1.000763	1.042169	1.570009
472	0.423472	0.951972	1.360611	1.357109
473	0.355865	0.395285	0.919253	1.791735
474	0.639787	1.006843	1.573217	2.4805
475	0.845945	1.117188	2.228269	2.3549
476	0.71554	1.176994	2.049627	1.446462
477	0.808819	0.41103	2.080376	2.021072
478	0.064025	1.887976	0.59561	0.355145
479	0.059543	0.968876	0.125973	1.734355
480	0.501962	0.1335	1.25263	2.633929
481	0.162343	1.032699	0.673889	1.155473
482	0.111115	0.606413	0.450782	1.073142
483	0.407957	1.401925	1.447808	1.664073
484	0.937384	0.577544	2.296363	2.589696
485	0.895608	0.375732	2.401939	2.344374
486	0.608036	0.875139	1.783151	2.016365
487	0.28169	1.143191	0.398305	0.870874
488	0.165125	2.184834	0.203994	0.252505
489	0.693133	0.352949	1.847141	0.634914
490	0.760987	0.533314	1.999507	0.868315
491	0.758055	0.422814	1.983068	1.368169
492	0.647998	0.470375	1.685019	1.351014
493	0.453909	0.069877	1.166444	2.261277
494	0.246358	0.53148	0.546292	1.941882
495	0.355612	0.68821	0.729146	1.397651
496	0.705931	2.469356	1.13372	1.852825
497	0.520794	3.438388	0.359042	1.616098
498	0.356326	0.084143	0.915429	1.811331
499	0.494121	1.158886	0.957191	1.81227
500	0.099675	1.097761	0.538946	0.30608
501	0.142742	0.40745	0.252538	0.707488
502	0.336376	2.020781	0.287669	1.215185
503	0.33681	0.687678	0.669702	1.359233
504	0.591747	0.50492	1.665581	1.335968

505	0.093722	0.70784	0.435308	1.478234
506	0.083982	2.210648	0.698329	0.762826
507	0.08043	2.101795	0.803571	1.026705
508	0.170424	0.920285	0.687388	0.591099
509	0.139582	2.611807	0.416999	0.518203
510	0.250748	1.500081	0.249611	0.823852
511	0.263009	1.245304	0.325809	0.520523
512	0.328241	2.516547	0.125179	0.521838
513	0.10739	2.446111	0.975015	1.400522
514	0.05913	1.365401	0.541381	0.541384
515	0.136127	1.53127	0.097015	0.757776
516	0.263271	0.697416	0.817345	0.978653
517	0.654079	2.307004	1.058311	0.643957
518	0.207364	0.223716	0.541933	1.172814
519	0.190247	0.227503	0.489857	1.051328
520	0.177049	1.347107	0.075893	0.820754
521	0.097609	1.192526	0.089731	1.330793
522	0.159403	1.034205	0.28919	2.258746
523	0.084843	0.757933	0.04334	1.881761
524	0.451763	0.422814	1.26877	0.78714
525	0.109595	1.033142	0.547144	1.700828
526	0.290802	0.906385	0.517703	2.850771
527	0.135553	0.106261	0.332791	2.177554
528	0.464312	0.532684	1.323967	1.568255
529	0.086567	0.687544	0.060721	0.300297
530	0.596273	1.891851	1.012303	0.398303
531	0.031358	0.307777	0.029018	0.131579
532	0.39793	0.614412	0.862301	1.112161
533	0.075919	0.687544	0.369971	0.985626
534	0.192624	0.225482	0.431376	1.583836
535	0.378488	1.125	0.651847	1.683435
536	0.368072	0.161059	0.901788	1.276025
537	0.149308	1.125976	0.705445	1.477201
538	0.114702	1.037034	0.589556	1.186455

539	0.413373	0.539459	0.910725	1.502114
540	0.231054	0.521568	0.445647	1.365755
541	0.104398	1.001951	0.017857	0.698517
542	0.020906	0.195313	0.020089	0.186562
543	0.098531	1.375355	0.578379	0.259155
544	0.529916	0.307777	1.427917	0.421922
545	0.516283	1.533819	1.737611	1.461662
546	0.268042	1.038798	0.537293	2.784164
547	0.361928	0.882813	1.089087	2.686519
548	0.375358	0.876255	0.771172	1.092226
549	0.07091	0.503891	0.125656	0.681361
550	0.06693	0.356305	0.071463	0.249882
551	0.225755	1.875146	0.045142	0.998147
552	0.229587	0.689096	0.393491	1.402369
553	0.132971	0.356305	0.437779	1.324855
554	0.022917	0.569884	0.153613	0.290488
555	0.009228	0.87224	0.272577	0.625595
556	0.213508	0.64504	0.549035	0.124253
557	0.132858	1.25022	0.496098	0.058145
558	0.320237	0.682197	0.629528	0.279273
559	0.205192	0.532168	0.413543	0.382247
560	0.03335	0.471088	0.113642	0.138617
561	0.114587	0.939581	0.033482	0.304895
562	0.006998	0.190086	0.06715	0.426511
563	0.46567	2.292473	0.544867	0.894135
564	0.053931	0.197642	0.135776	0.765002
565	0.281251	2.846496	0.097015	0.753522
566	0.003579	0.534057	0.143969	1.171701
567	0.097222	0.781289	0.026879	0.067034
568	0.086684	0.892815	0.216138	0.828132
569	0.281765	0.408945	0.742042	0.876012
570	0.52255	0.85081	1.226796	0.401648
571	0.220732	0.157998	0.596283	0.183345
572	0.48249	1.459077	1.444831	1.155321

573	0.11959	2.962421	1.054273	1.471479
574	0.128484	0.831251	0.511511	0.980154
575	0.247504	1.191195	0.889637	0.872013
576	0.314069	0.354329	0.715679	0.412148
577	0.196834	0.939094	0.301893	0.199724
578	0.454105	0.513549	1.150715	0.317972
579	0.122282	0.656994	0.254621	0.164277
580	0.082757	0.117188	0.179462	0.874052
581	0.154787	0.816247	0.624298	0.969221
582	0.496953	0.787824	1.079307	1.00855
583	0.394507	0.593801	0.894608	0.152795
584	0.303448	1.187603	0.828702	0.074747
585	0.398493	0.385988	0.991898	0.227839
586	0.677929	2.959896	0.897668	0.356714
587	0.651974	4.12645	0.497863	0.37141
588	0.129503	0.936067	0.065649	0.78991
589	0.853837	5.711066	0.563849	1.219147
590	1.008255	6.509758	0.736786	1.399249
591	0.385671	4.037914	0.161965	2.471187
592	0.215977	0.119253	0.543585	1.062994
593	0.199494	0.320313	0.600347	0.557904
594	0.010453	1.004385	0.260549	0.035498
595	0.326399	0.81265	0.607147	0.458813
596	0.809035	0.437779	1.955403	0.004502
597	0.598921	1.513045	1.107793	0.459363
598	0.825075	1.162567	1.789929	0.406197
599	0.645358	0.85081	1.416637	0.436514
600	0.475949	0.117188	1.1986	0.153936
601	0.343399	0.069877	0.870616	1.08263
602	0.114214	0.257694	0.36705	6.644725
603	0.487439	0.60374	1.425219	3.565645
604	0.268813	0.535883	0.844116	0.166143
605	1.014745	1.602991	2.152102	0.031389
606	0.436345	2.00244	1.693448	0.060426

607	0.470887	0.098821	1.232307	0.434168
608	0.478632	1.449529	0.822205	0.466494
609	0.539526	1.201628	1.044032	1.013007
610	0.37144	1.282393	0.588782	0.82847
611	0.558899	1.326401	1.058892	1.103574
612	0.618925	1.027574	1.298332	0.719686
613	0.570143	1.983098	0.899598	0.774664
614	0.168914	1.432481	0.026879	1.012668
615	0.227399	0.161059	0.540529	1.049655
616	0.328198	0.651443	1.029637	0.221288
617	0.649032	0.689096	1.474325	0.41848
618	0.674801	0.915497	1.474068	0.89456
619	0.031262	0.348073	0.025254	0.39878
620	0.467663	1.878447	0.666425	0.918995
621	0.680569	2.571832	1.015318	0.086513
622	0.899028	5.299991	0.802678	0.304534
623	0.63472	1.84514	1.10556	0.050924
624	0.364378	0.676041	0.743893	0.346756
625	0.302264	2.232585	0.13954	0.75542
626	0.101648	0.119253	0.23607	0.845467
627	0.11959	0.139754	0.33908	0.828387
628	0.252843	0.373124	0.543562	1.008341
629	0.791804	0.502982	1.892373	0.437704
630	0.505832	1.450203	0.887529	1.270848
631	0.195251	1.502602	0.087965	1.536242
632	0.466114	0.159344	1.239048	1.729234
633	0.364154	1.130223	0.615311	1.117724
634	0.139937	3.113259	0.529973	0.252952
635	0.093766	0.062986	0.223225	0.570791
636	0.30312	0.095043	0.798424	0.81028
637	0.202138	0.461996	0.391052	0.990051
638	0.185796	0.236449	0.544643	1.111448
639	0.344636	0.007813	0.888438	0.826108
640	0.196947	0.833415	0.744506	0.773375

641	0.186056	0.789063	0.698889	0.321125
642	0.304767	0.492683	0.647568	0.040281
643	0.080162	0.039063	0.202732	0.240549
644	0.598659	3.384688	0.572631	0.505367
645	0.500867	2.623744	0.539218	0.400057
646	0.090278	0.48914	0.37169	0.680612
647	0.486756	1.555159	0.80736	0.599182
648	0.323588	1.590549	0.377866	0.185861
649	0.197429	0.772174	0.287669	0.344051
650	0.20848	1.754806	0.036337	0.079863
651	0.182622	0.069877	0.486197	0.226193
652	0.304856	0.371402	0.679778	0.25549
653	0.258121	0.878481	0.412747	0.145245
654	0.024445	0.632764	0.242236	0.303067
655	0.298653	0.007813	0.767026	0.494091
656	0.06693	0.720954	0.055804	0.126924
657	0.049715	0.094075	0.102993	0.078538
658	0.15345	0.723869	0.59561	0.135943
659	0.033225	0.771818	0.135132	0.555762
660	0.100278	0.773082	0.046448	0.19678
661	0.195071	0.37443	0.395745	0.299222
662	0.136218	0.282981	0.270458	0.025376
663	0.111814	0.032212	0.296539	0.192301
664	0.279579	0.636035	0.900414	0.247499
665	0.266797	0.426265	0.806249	0.106509
666	0.241993	0.178324	0.671786	0.094874
667	0.494243	0.726856	1.063709	0.272606
668	0.145419	1.083462	0.072295	0.048803
669	0.135961	0.16313	0.393263	0.073898

Appendix G Sinuosity index of each reach

Reach	Year				
	1952	1988	1992	2006	2020
1	1.005407	1.001001	1.011655	1.015283	1.000468
2	4.126879	4.510347	4.511257	4.551392	4.520541
3	2.276357	2.248527	2.23972	2.226642	2.1185
4	1.025263	1.016414	1.013597	1.012795	1.002236
5	3.716255	3.341047	3.332472	3.400438	3.372572
6	1.008532	1.003593	1.001813	1.007223	1.005884
7	1.064035	1.065945	1.071279	1.05775	1.059422
8	1.060705	1.066354	1.066941	1.058359	1.059903
9	1.712218	1.543599	1.523399	1.495475	1.505549
10	2.466768	2.880022	2.873059	2.868952	2.842203
11	1.029015	1.020144	1.017362	1.023501	1.010327
12	2.498102	2.432521	2.453185	2.464726	2.446214
13	1.281496	1.258186	1.266727	1.259267	1.248035
14	1.130278	1.11305	1.112564	1.107483	1.109061
15	1.293208	1.283813	1.276754	1.272298	1.276096
16	6.829019	6.792132	6.763434	6.790598	6.628847
17	1.091055	1.078925	1.090796	1.071971	1.064632
18	1.699423	1.690116	1.703772	1.672332	1.695236
19	1.029272	1.039259	1.029892	1.019384	1.025177
20	1.536855	1.502402	1.346802	1.317854	1.318113
21	2.406332	2.471221	2.155984	2.147388	2.210699
22	1.813475	1.848328	1.869241	1.869129	1.888762
23	1.041874	1.034711	1.043629	1.033441	1.033672
24	2.67128	2.619535	2.619082	2.60983	2.595152
25	1.009858	1.01664	1.001564	1.010728	1.005667

Appendix I Detail of each cross-sectional data

Index	Station				
	1	2	3	4	5
Width (Meter)	70	88	133	104	104
Cross-sectional area (Square Meter)	319.144	390.1	325.14	696.24	479.8079
Maximum Depth (Meter)	6.35	7.44	5.4	9.68	7.14
Average Depth (Meter)	4.552282	4.432954545	2.444662	8.337797	4.613537
Depth at center line (Meter)	5.064	7.376	3.4	9.305147	6.854
Depth at median line (Meter)	5.058429	6.110936	5.174088	9.610747	6.853368
X Value (Meter)	-12	20	34.5	11	-22
W' Value (Meter)	-0.17408	8.6133	19.28865	1.045	0.036
A' Value (Square Meter)	0.881056	58.08351292	82.69129	9.883554	0.246733
Aw value	0.004974	0.195756818	0.290055	0.020096	0.000692
Aa value	0.005521	0.297787813	0.50865	0.028391	0.001028
Awa value	2.75E-05	0.058293995	0.147537	0.000571	7.12E-07
A1 value	0.429926	0.45848945	0.823972	0.22006	0.440731
A2 value	0.121714	0.185308954	0.450947	0.030513	0.155951
Area of right (Square Meter)	160.453	146	81.3625	338.2497	239.6631
Area of left (Square Meter)	158.691	244.1	243.7775	357.9903	240.1448
A*	0.005521	-0.251473981	-0.49952	-0.02835	-0.001

VITA

NAME	Pawat Wattanahareekul
DATE OF BIRTH	14 August 1996
PLACE OF BIRTH	Khon Kaen
INSTITUTIONS ATTENDED	High School: Demonstration School Khon Kaen University (Suksasart) Bachelor's degree (B.Sc. in Geology) : Chulalongkorn University Master's degree (M.Sc. in Geology) : Chulalongkorn University