TECHNISCHE UNIVERSITÄT MÜNCHEN

Geodetic Support for Flood Risk Management in Thailand with Prevention and Adaption Methods

Dissertation

by

Rattikarn Khambud

Lehrstuhl für Geodäsie

Ingenieurfakultät Bau Geo Umwelt

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Abstract

In the year 2011, massive flooding occurred around the Chao Phraya River, Thailand. These floods had a tremendous impact on the country's communities and economic systems which resulted in many victims and homeless as well as substantial loss of property. There are many factors that likely caused these flooding events. Two main influential issues are climate change and stimulating anthropogenic interventions. The central region of Thailand had flooding problems previously that have been attempted to be reduced by using structural (hard-engineering) and non-structural methods. Nevertheless, the process of planning and implementing the action plans still has not worked out so far for long-term projects. Some of those solutions may create new risks for other factors such as public or private walls for flood protection, making concrete embankment inefficient, destroying river-landscapes or have environmental impacts.

Understanding the performance of many European countries and realizing how efficient the national river cooperation can work hand in hand for solutions to flooding catastrophes is one crucial means of managing flood risk. For example, a related section defined by the EU policy is a legal basis for transnational perspectives within the differences of flood protection and planning law among EU communities e.g. along the Elbe River. Besides, preventative flood management measures of spatial planning and the remarkable international cooperating projects on the Rhine River (room for the river concepts), the case of water retention areas nearby Cologne and the future plans of the Danube River line in the "Flood Protection Action Program 2020" of the Bavarian State of Germany were reviewed in this work. The most interesting practices are highlighted on the new Danube River and the Danube Island in Vienna, Austria, which is a quality program of flood prevention. The clever design in conjunction with other enhancements allows for the increased capacity of water flow while having a creative design that functions as a recreation area in non-flooding seasons and can render plenty of benefits for local and national communities. This research concludes that the best benefit of geodetic approaches through water and land management in order to significantly minimize flooding in Central Thailand is a new artificial river. The new artificial Chao Phraya River would encounter challenging conditions of low-lying areas, high density population and forest areas.

This solution is properly supported by geodetic approaches and utilizes new advanced satellite surveys from the German TanDEM-X and TerraSAR-X single-pass SAR interferometry of the DLR (German aerospace center). These surveys demonstrate results with immense potential. The superior high-resolution terrain information of Hydro-DEM (12 m position and 2 m height accuracy) geo-information were fed into a Geographic Information Systems (GIS) ArcGIS to find the optimum track of the relieving river. Also, the river capacity and cross section were designed and calculated respectively. The key factors in the design of the new river channel will be that it avoids existing human settlements and forest areas. These considerations will lead to decreased land relocation and deforestation, thereby having less negative impacts as a result of the research project. This method, together with a more supportive system of water retention in various areas of functional land management in urban and rural areas illustrates encouraging results. Furthermore, a future plan of dealing with hydro-meteorological phenomena working in conjunction with the local authority encourages cooperation by raising awareness locally while establishing a communication channel. The community flood policy and plans for long-term optimized flood risk management can take a multi-functional approach by utilizing cooperative efforts from both local and national entities.

Keywords: *Geodetic approaches, Digital Elevation Model (DEM), Land and Environment, Climate change, New artificial river, Flood risk management*

Zusammenfassung

Im Jahr 2011 kam es zu schwerwiegenden Hochwassern um den Fluss Chao Phraya in Thailand. Diese Hochwasser hatten massive Auswirkungen auf die Gemeinschaften des Landes und wirtschaftliche Organisationen, infolgedessen viele Betroffene obdachlos wurden oder einen hohen materiellen Schaden durch Verlust von Eigentum erlitten. Viele Faktoren trugen zum Auftreten der Hochwasser bei. Die zwei hauptsächlichen Einflüsse sind der Klimawandel und anthropogene Eingriffe. Thailands Zentralregion war schon zuvor von Hochwasser betroffen, woraufhin versucht wurde, diese Probleme sowohl mit Baumethoden (suboptimale Konstruktionen) und organisatorischen Maßnahmen zu lösen. Die Planung und Implementierung der Aktionsprogramme konnten weiterhin nicht in Langzeit-Projekten umgesetzt werden. Manche dieser Lösungen, z. B. staatliche oder private Wälle zum Schutz vor Hochwasser oder ineffiziente Betondämme, können neue Risiken in anderen Bereichen bergen, wie die Zerstörung von Flusslandschaften und negative Einflüsse für die Umwelt.

Die effiziente Kooperation der europäischen Länder in Belangen der nationalen und internationalen Gewässer und die nahtlose Zusammenarbeit an der Lösung für Hochwasser Probleme sind wichtige Bestandteile, des Hochwasserrisikomanagements. Ein Beispiel für die Bereiche die die EU Richtlinien abdecken ist das Schaffen rechtlicher Grundlagen für transnationale Perspektiven trotz Differenzen der europäischen Gemeinschaften im Hochwasserschutz und der planungsbedingten Gesetze beispielsweise in Zusammenhang mit der Elbe. Weitere Beispiele sind das vorbeugende Hochwassermanagement mithilfe von Raumplanung, die beeindruckende internationale Kooperation an Projekten am Rhein („Room for the river"-Konzept), die zukünftig geplanten Flutpolder bei Köln an der Donau und das „Hochwasserschutz Aktionsprogramm 2020" des Freistaates Bayern. Die interessantesten Praktiken sind am Beispiel der Donauinsel in Wien hervorgehoben. Die durchdachte Verzweigung der Donau erlaubt mithilfe noch anderer Verbesserungen einen größeren Wasserdurchfluss während die kreative Umsetzung des Projektes auf der Insel ein Erholungsgebiet errichtet und damit den Anwohnern zusätzliche Vorteile bietet. Innerhalb dieser Forschungsarbeit stellt sich heraus, dass die beste Methode zur signifikanten Verringerung von Hochwasserrisiken in Thailand mithilfe von geodätischen Herangehensweisen in Wasserwirtschaft und Landmanagement ein neuer künstlich angelegter Flusslauf ist. Ein künstlicher Flusslauf sieht sich dennoch Herausforderungen wie tiefliegender Gebiete, stark bevölkerter Städten und Wäldern gegenüber.

Diese Lösung ist fundiert durch geodätische Herangehensweisen und bedient sich an der fortschrittlichen Satelliten Untersuchung der deutschen TanDEM-X und TerraSAR-X Single-Pass SAR Interferometrie des DLR. Damit kann diese Untersuchung Resultate mit immensem Potential vorweisen. Die Gewässer-DEM-Daten mit bisher unerreichter Auflösung (12 m Positions- und 2 m Höhengenauigkeit) wurden als geologischer Datensatz im Geographic Information Systems (GIS) Programm ArcGIS als Grundlage benutzt um den optimalen Verlauf des Entlastungkanals zu finden. Ein wesentliches Element in der Planung des Verlaufes ist die Vermeidung bereits existierender Siedlungen und Waldgebieten. Diese Berücksichtigungen führen letztendlich zu einer Abnahme der Umsiedlungs- und Entwaldungsmaßnahmen und tragen allgemein zu weniger negativer Auswirkungen bei. Zusammen mit weiteren unterstützenden Flutpoldern in städtischen und ländlichen Gebieten, die mit Methoden des Landmanagements erkundet wurden, können erhebliche Verbesserungen im Hochwasserschutz festgestellt werden. Des Weiteren ist ein Zukunftsplan für das Verhalten bei meteorologischen Wasser-Phänomenen zu empfehlen. Hierzu gehört die Kooperation von Gemeinden, das Sensibilisieren auf die Notwendigkeit einer Hochwasser Richtlinie und das Erstellen von Langzeit-Plänen zur kooperativen Optimierung des Hochwasserrisikomanagements von sowohl der Gemeinden als auch nationaler Instanzen.

Keywords: *Geodätische Herangehensweise, Digital Elevation Model (DEM), Land und Umwelt, Klimawandel, Neuer künstlich angelegter Fluss, Hochwasserrisikomanagement*

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Abbreviations

ASTER GDEM	The Advanced Space borne Thermal Emission and Reflection Radiometer and Global Digital Elevation Model
DEM	The Digital Elevation Model
DGR	The Department of Ground Water Resources, Thailand
DLR	The German Aerospace Center, Germany
DMR	The Department of Mineral Resources, Thailand
DOH	The Highway Department of Thailand
DPT	The Department of Public work Town and Country planning, Thailand
DSM	The Digital Surface Model
DTM	The Digital Terrain Model
DWR	The Department of water resources, Thailand
EC	The European Commission
EIA	Environmental Impact Assessment
EU	The European Union
FAO	The Food and Agriculture Organization of the United Nations
FIG	International Federation of Surveyors
GIS	Geographic information system
GIZ	German International Cooperation, Germany
GPS	The Global Positioning System
ICPDR	International Commission for the Protection of the Danube River
ICPER	International Commission for the Protection of the Elbe River
ICPR	International Commission for the Protection of the Rhine
IPCC	The intergovernmental Panel on Climate change
IWRM	The Integrated Water Resource Management
JICA	Japan International Cooperation Agency
LfU Bavaria	The Bavarian Environmental Agency, Germany
METI	Ministry of Economy, Trade and industry, Japan
MoNRE	Ministry of Natural Resources and Environment
NASA	The United States National Aeronautics and Space Administration
NGO	Non-governmental organization
NSO	National Statistical Offices, Thailand
ONEP	The Office of National Resources and Environmental Policy and Planning
RFD	The Royal Forest Department, Thailand
RID	The Royal Irrigation Department, Thailand
RTN	The Royal Thai Navy, Thailand

RTSD	The Royal Thai Survey Department, Thailand
SCWRM	The Strategic Committee for Water Resource Management, Thailand
SEA	Strategy Environmental Assessment
SIA	Social Impact Assessment
SRTM	Shuttle Radar Topography Mission
TMD	The Thai Meteorological Department, Thailand
UNECE	The United Nations Economic Commission for Europe
UNFCCC	The United Framework Convention on Climate Change
UNFPA	The United Nations Population Fund
UN-Habitat	The United Nations Human Settlement Programme
UNISDR	The United Nations Office for Disaster Risk Reduction

Measurement Units

Length Units

mm	millimeter(s)
cm	centimeter(s)
m	meter(s)
km	kilometer(s)

Areal Units

mm^2	square millimeter(s)
cm^2	square centimeter(s)
m^2	square meter(s)
km^2	square kilometer(s)
Rai	Thai areal Unit (1,600 square meters)

Volume Units

cm^3	cubic centimeter(s)
m^3	cubic meter(s)
ltr.	Liter(s)
ml	milliliter

Time Units

s, sec	second(s)
min	minute(s)
h, hr	hour(s)
d, dy	day(s)
y, yr	year(s)

Velocity Units

cm/s	centimeter(s) per second
m/s	meter(s) per second
km/h	kilometer(s) per hour

Other Units

%	percent
°C	Degree centigrade
Baht	Thai currency
GWh	Gigawatt hours
HQ100	A one-hundred-year flood
MSL	Mean sea level

1 Introduction

1.1 Flood Challenge in Thailand

Massive floods occur repeatedly and more frequently while also creating more challenges in our changing world. Thailand especially was faced by the catastrophic flood events in the year 2011.

This research focuses on the flood issues and the combination of measures and geodetic approaches which attempt to achieve an optimized solution for flood risk management by balancing between the developments of new structures and staying in harmony with the environment in the Ayutthaya province and the surrounding central area of Thailand.

1.2 Motivation

Flood impacts are one of the most significant natural disasters in the world. Extreme floods are the most widely experienced catastrophic geologic hazards. Especially, flood hazards have been increasing from uncertain long-time climate change and human activities (IPCC, 2007a).

Thailand is the seventh in the ranking of flood prone areas in the world (Preventionweb, 2013). The Thai national official statistic reported that from 2002-2008 Thailand had an annual average of flooding of approximately 10 times per year.

Thailand encountered many devastating floods in its history. The World Bank (2012) reported that in 2011 the massive flood, which was caused by excessive and continuing rainfall from successive, powerful monsoons, inundated more than six million hectares of land in 66 of the country's 77 provinces. The total cost of damage and losses estimated was 1.43 trillion baht (45.5 billion USD) and the flood affected more than 13 million people. From the world natural catastrophe in 2011, Thailand was impacted from floods (August – November) and landslides which resulted in 813 fatalities (Munich RE, 2012).

After the floods in 2011, many organizations purposed to minimize the flood problems by mitigation and adaptation. The methods were used in various alternative approaches. However, it seems that those miscellaneous alternative options still cannot deal with the increasing extreme floods in Thailand efficiently.

Due to massive flooding, the influences from human made structures that occur in the critical condition of the flat land area, will be an additional challenge for the natural drainage patterns and flow obstruction. For example, some action plans of the flood protection programme such as public or private flood walls, huge concrete dykes along the Chao Phraya River and hard-engineered constructions are probably creating new challenges in the future flood solution.

After the flood in 2011, the reflection of practical works was begun and the created problems were noticed, such as the main river that became narrow, the water run-off which was blocked with constructions, the lack of drainage areas and the disregard of environmental issues, etc.

The method to deal with flood issues should be multi-functional. The main reason is to minimize flood disasters. The extra benefit of creating new sustainable environments that develop land areas for free space communities is an excellent byproduct.

According to Wunderlich (2016), to manage flooding on environmental approaches and to build surveys together with geodetic monitoring, it should be actively aimed for:

- *Sustainable planning*
  - *detailed mapping of property or real estate for modification planning*
  - *mapping of topography & current land ownership structure for regional planning*
  - *…etc.*
- *Prevention of hazards (flooding)*
  - *Natural threats*
    - *environmental contamination by industrial plants in case of flooding*
    - *monitoring and evaluation of slope & embankment stability*
    - *understanding of environmental risk management*
    - *… etc.*
  - *Technical threats*
    - *investigation of static problems of non-documented structures*
    - *collapse of structures due to imperfections in static or dynamic behavior*
    - *… etc.*

Therefore, the solution of prevention of hazards such as flooding and landslide will demand sustainable planning and techniques.

In flood disaster areas, one important factor that we cannot deny is that excess water is the main cause of flooding (Göttle, 2015). Many issues of floods cannot avoid an increasing pattern of larger precipitation. Ground water also plays an important role in the stage of moistening and the absorption of surface water (ibid).

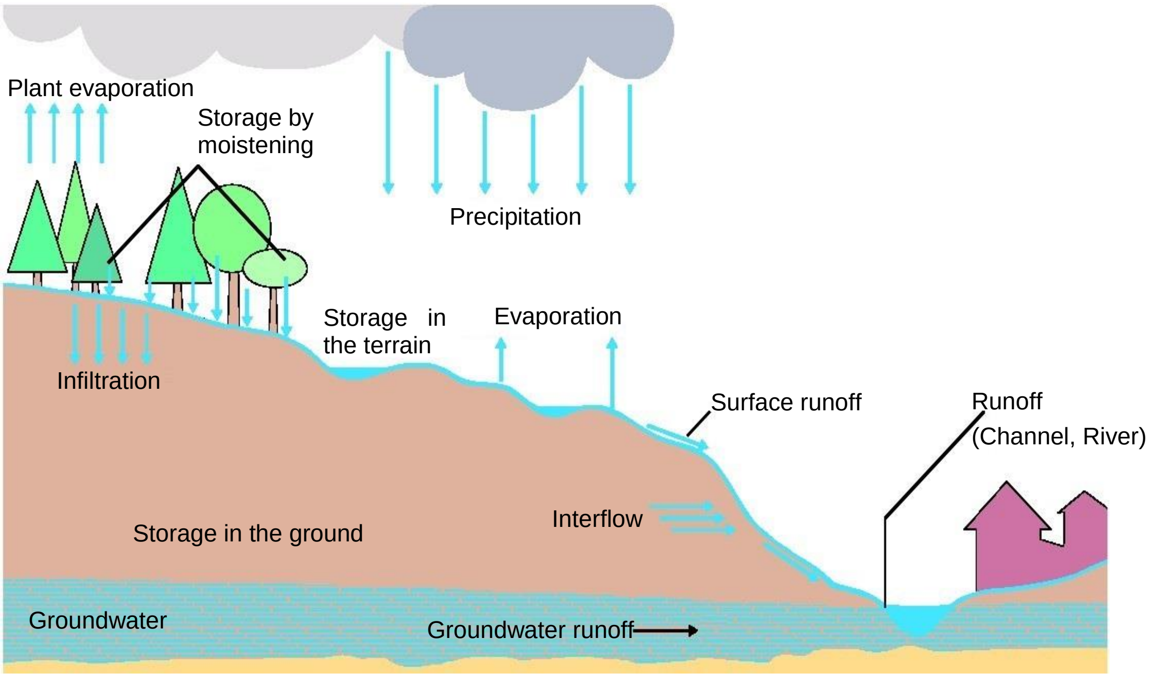

Figure 1.1 Water and flood situation (LfW 2004)

The water cycle (Figure 1.1) illustrates relevant factors in flooding. To begin with, the water from precipitation can be stored on the surface of plants or in the terrain (e. g. lakes) where parts of it steadily infiltrates the ground. The surface water will evaporate over time or form runoffs to lower lying areas for accumulation. The water that is infiltrating the ground is flowing downwards through the soil and forms the groundwater level.

More water from heavy rainfalls therefore means a higher groundwater level, which supports the formation of a flood in the low-lying areas. To determine the severity of a potential flood there are four points to consider:

- The amount of precipitation in the affected area
- The amount of precipitation that is discharging on the surface
- How close the discharge is to the next river
- The way the flood is proceeding

To help overcoming floods issues, the research's purpose is to combine prevention and adaptation. In terms of flood management not only structural methods[1] but also non-structural methods[2] (UNISDR, 2017) are considered. With geodetic and environmental approaches on flood solutions the idea of this research is to find the best possible flood management for Thailand.

Practical engineering in the areas of flood risk management can be developed to make risk informed investment decision. The opportunity of flood management should be concerning the improved environment as well (Sayers, 2012).

1.3 Objective of the research

1. Examine the flood situation in Thailand with respect to possible climate change and actual anthropogenic interventions.

2. Identify European and Thai flood management approaches in planning and practices.

3. Analyze Thai present situation and suitable prospects on flooding in the central area of Thailand.

4. Suggest the major scale measures on flood management with geodetic supporting approaches on an environmental friendly basis.

As with the type of instructions, flood catastrophic issues and management have been mainly involved which hydrology and river basin management. Together with the integrative water resources management, flood modeling and decentralized flood management, those are the essential factors for minimizing the increase of flood hazards and risks in the future.

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[1] Structural measures are concerned with physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems.

[2] The effectiveness of non-structural measures are measures not involving physical construction which apply knowledge, practice or agreement to reduce disaster risks and impacts, in particular through policies and laws, public awareness raising, training and education. For example, land use spatial planning, public awareness etc.

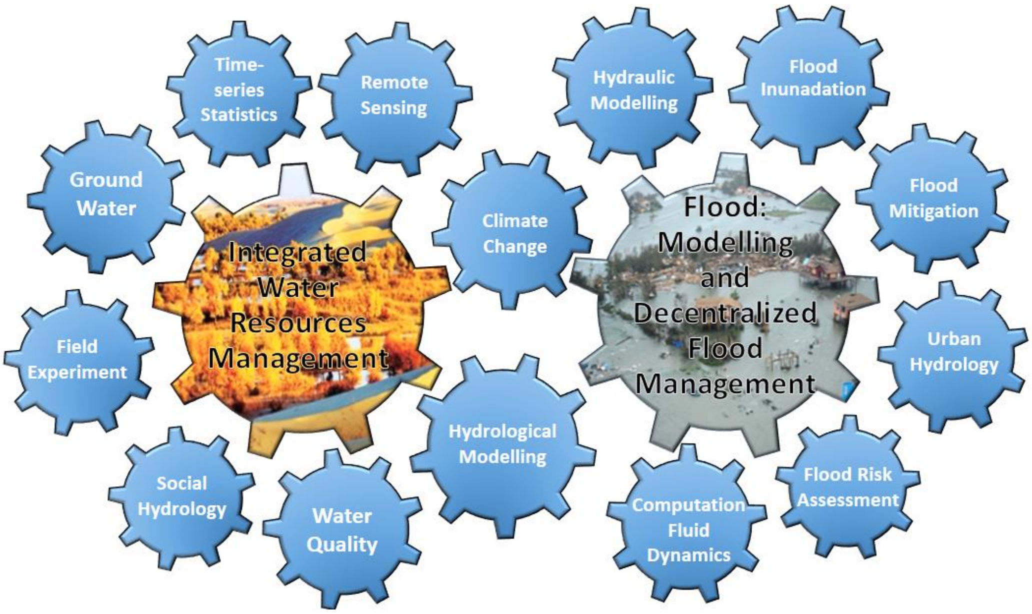


Figure 1.2 Hydrology and River Basin Management (Disse, 2017)

Managing flood risk empowers professionals to learn the integrated water resource management and flood modeling & decentralized flood management. This research applies the relation of factors to work on climate change, hydraulic modelling, flood inundation, flood mitigation, urban hydrology, flood risk assessment, remote sensing and social hydrology.

According to UNISDR (2009)[3] Flood risk management is the way how the best option can be found to deal with a natural hazard: *The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effect of a hazard.*

RISK = HAZARD x VULNERABILITY x AMOUNT

- Hazard = Probability of event with a certain magnitude
- Vulnerability = Degree of damage

A flood risk is defined as the likelihood of a flood disaster which causes damage and endangers human lives, the environment and economic activities. It can be considered as a real threat to the communities in the flood hazard areas (COM, 2006).

Strobl and Zunic (2006) defined the factors of climate change and anthropogenic measures which cause an increasing of flood risk, such as:

- Flow degradation
- Embedding
- Human settlement
- Use of floodplains.

The increased risk of flooding is not only from natural hazards, it is also on anthropogenic factors such as increased human settlement and encroachment of housing and infrastructure

[3] Flood risk management is the current concept on how to deal with natural hazards and flooding best. It is a well-established approach which concerns the prevention, protection, preparedness, emergency responses, recoveries and lessons-learned from flooding.

in floodplains in lower-lying areas. The development of urban area causes make less drainage and increases impervious area (Sene, 2013).

The perception of this research will apply information from the physical, social, economic, and environmental factors mitigating the risk by flood management. Especially, the poor design and construction of buildings, inadequate protection of properties, lack of public information and awareness, limited official recognition of risks and preparedness measures and disregard for wise environmental management will be concerned in the research.

1.4 The State of the Art of Geodetic Approaches applied

Significant for the challenges of the low-lying flood plain areas is the important data collection and analysis with geodetic information (Wunderlich, 2016). This supports the success of the design and planning of flood prevention.

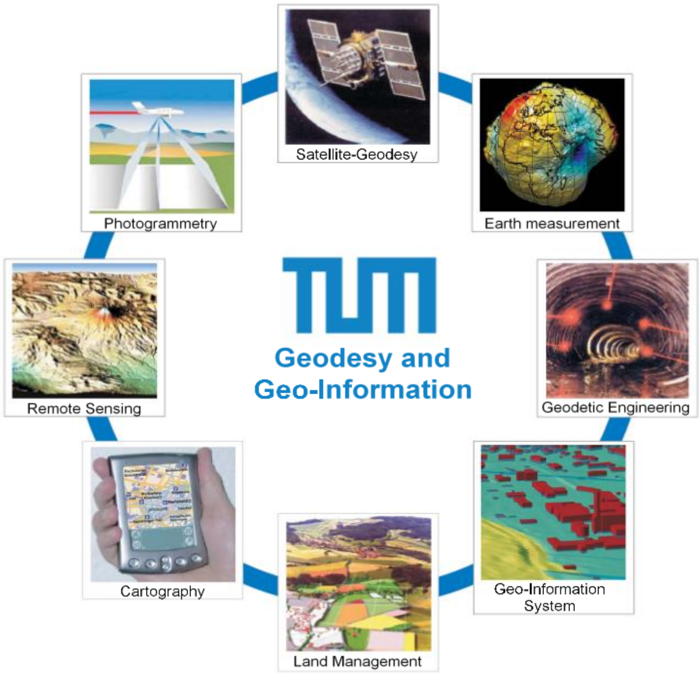


Figure 1.3 Geodesy and geo- information (Lecture Environmental Engineering; Barth, 2015)

Hence, it is important to provide basic information of the different branches of geodesy and geo-information. Figure 1.3 illustrates the relevance of the satellite geodesy, earth observation, geodesy engineering, geoformation systems, land management, cartography-mapping, remote sensing and photogrammetry that will combine these multi-knowledges and disciplines under unified measures of geodesy and geo-information.

One main method with the potential prospects are geodetic investigations for flood risk management in central region of Thailand. Design and planning of flood prevention and adaptation will focus on the design of geodetic engineering with proper land management. These will also apply the use of satellite and remote sensing information.

Therefore, the desired outcome of this research in the technical aspect is to implement a combination of geodetic approaches with various interdisciplinary developments. There will also be considerations for flood risk management aimed at flood adaptation for future development while minimizing risk to the local inhabitants and habitat.

Geodetic technology and interdisciplinary sciences are applied in this research for the design and planning of flood management which is concerned with these five main issues:

- Geodesy (Surveying work)
- Remote sensing technology
- Digital Elevation Measure (Hydro-DEM)
- Geo information (Geographic information system; GIS and Mapping)
- Water and Land management

The Digital Elevation Model (DEM) data was provided from the DLR (German Aerospace Center). This is offering the opportunity for accurate planning and design of flood protection structures with high resolution data in this research work.

- It will be starting by providing the foundation of geodetic methods by using remote sensing, satellite imagery, DEM, GIS in-situ measurements to design and plan a new option of flood management such as a new river design and retention areas.
- More precise mapping will make less re-location impacts of local communities and environments. Moreover, the research will suggest the enhancing of the environmentally important aspects of flood adaptation.
- Following are suggestions on the circumstances for the central local organizations to manage the floods with various effective methods from well-experienced international co-operations from the European community.
- Finally, the result is expected to not only support the solution to the challenges of flooding in Thailand but also use the opportunity of creating potential activity areas together with the flood prevention and adaptation.

It is important to note that the results of the flood events caused by climate change and anthropogenic intervention will lead this research to understand the key components and to be able to fulfill those potential aims of this work.

1.5 Case Study Area

- The general case study area covers approximately 27,000 km^2 of the central area of Thailand and the Chao Phraya River, from the Nakhon Sawan province to the Ayutthaya province.
- The specific case study area of Ayutthaya[4] is 2,557 km^2 (as shown in the Map. 1.1)

The challenging condition of the case study area is the low-lying area in the lower part of the Chao Phraya Basin.

According to the government of Thailand (2011), the local properties, land cultivation and industrial estates of 12 provinces of the central region of Thailand were damaged. The key area of Ayutthaya – over 20,000 km^2 of farmland – were destroyed as well. The total area of damage represents approximately 24,351.6 km^2 and includes the metropolitan area of Bangkok with approx. 1,569 km^2. Three fourth of the whole area is an extreme subsidence area with more than 3 months of severe flood levels of around 3 to 4 meters.

Furthermore, this research aims to reduce the flood problems in the Ayutthaya province. Nevertheless, only solving the problems in the Ayutthaya city will not solve the problems in the whole area, as we know that environment cannot be divided by political administration boundaries.

Thus, the seven provinces of Nakhon Sawan, Uthai Thani, Chainat, Singburi, Lopburi, Angthong and Ayutthaya area were chosen in view of their adjacency to the main lower Chao Phraya River. The case study area attempts to observe the area covered by the river basins and the vicinity area which are naturally connected and have similar topographical characters and social structures (traditional community).

Those also are the reason for this research to select two case study areas in the central region and Ayutthaya and to first consider the major flood impacts of Thailand.

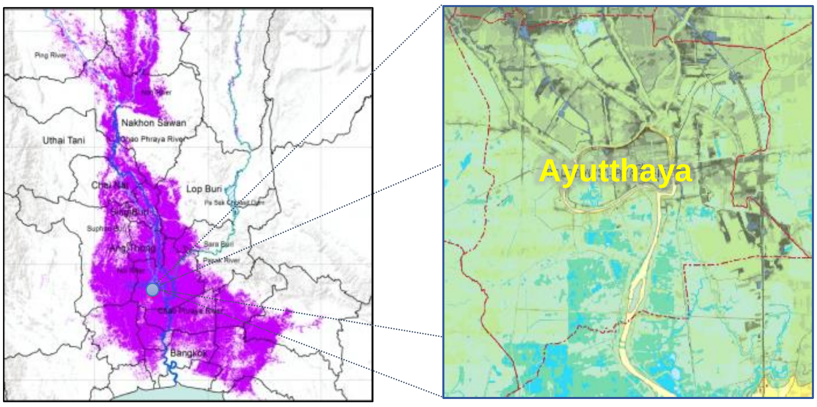
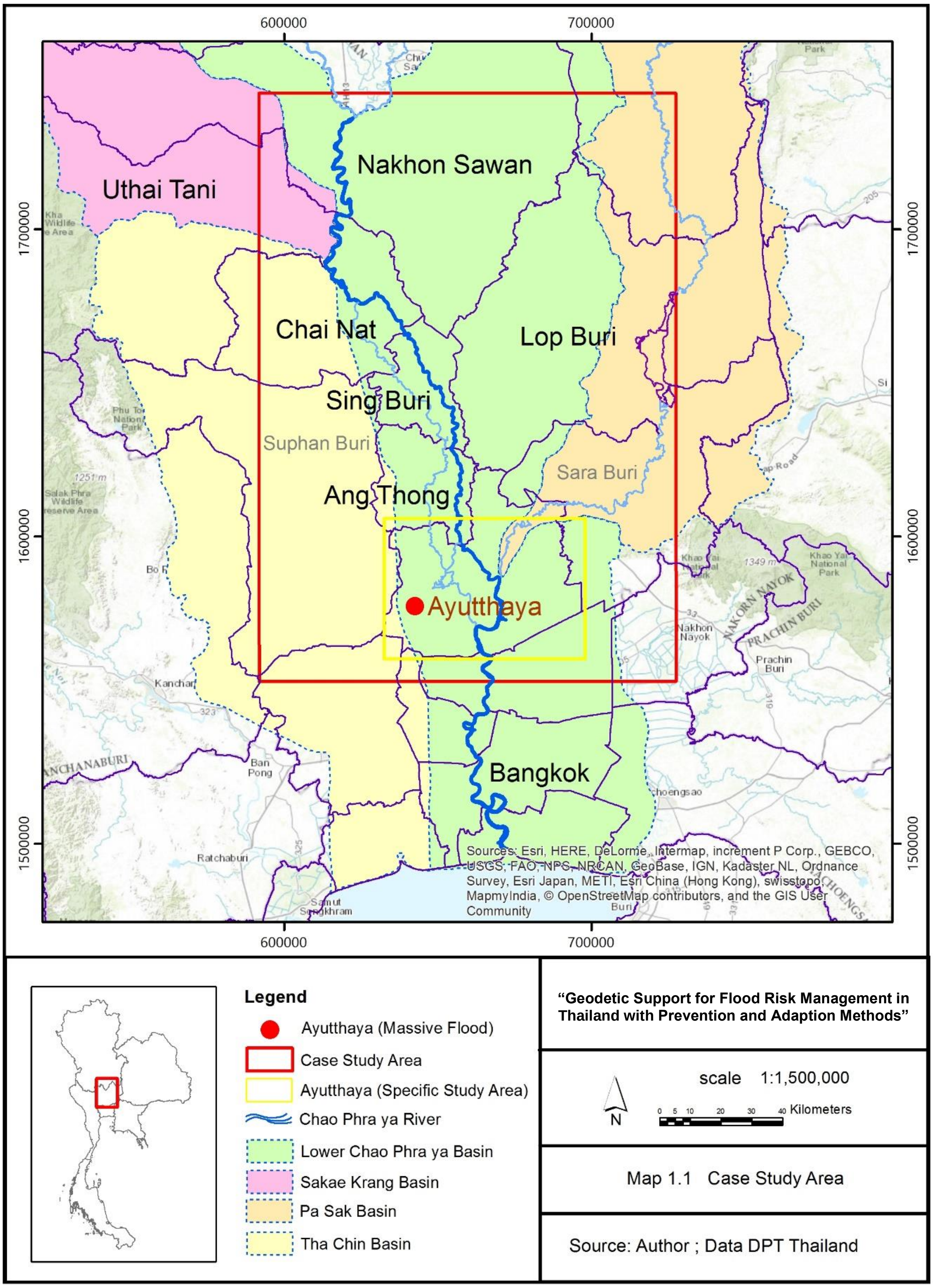


Figure 1.4 Thailand, Central region and Ayutthaya province: Flood Map[5] (GISDA, 2011)

[4] Ayutthaya is main famous the world historical heritage with UNESCO 1991. Meanwhile, the city of Ayutthaya located in the low land and flood risk has been facing with water submerged almost in every year.

[5] Data based on RADARSAT-2 (2011, October 17^{th})



Map 1.1 Case Study Area

1.6 Methodology and Data

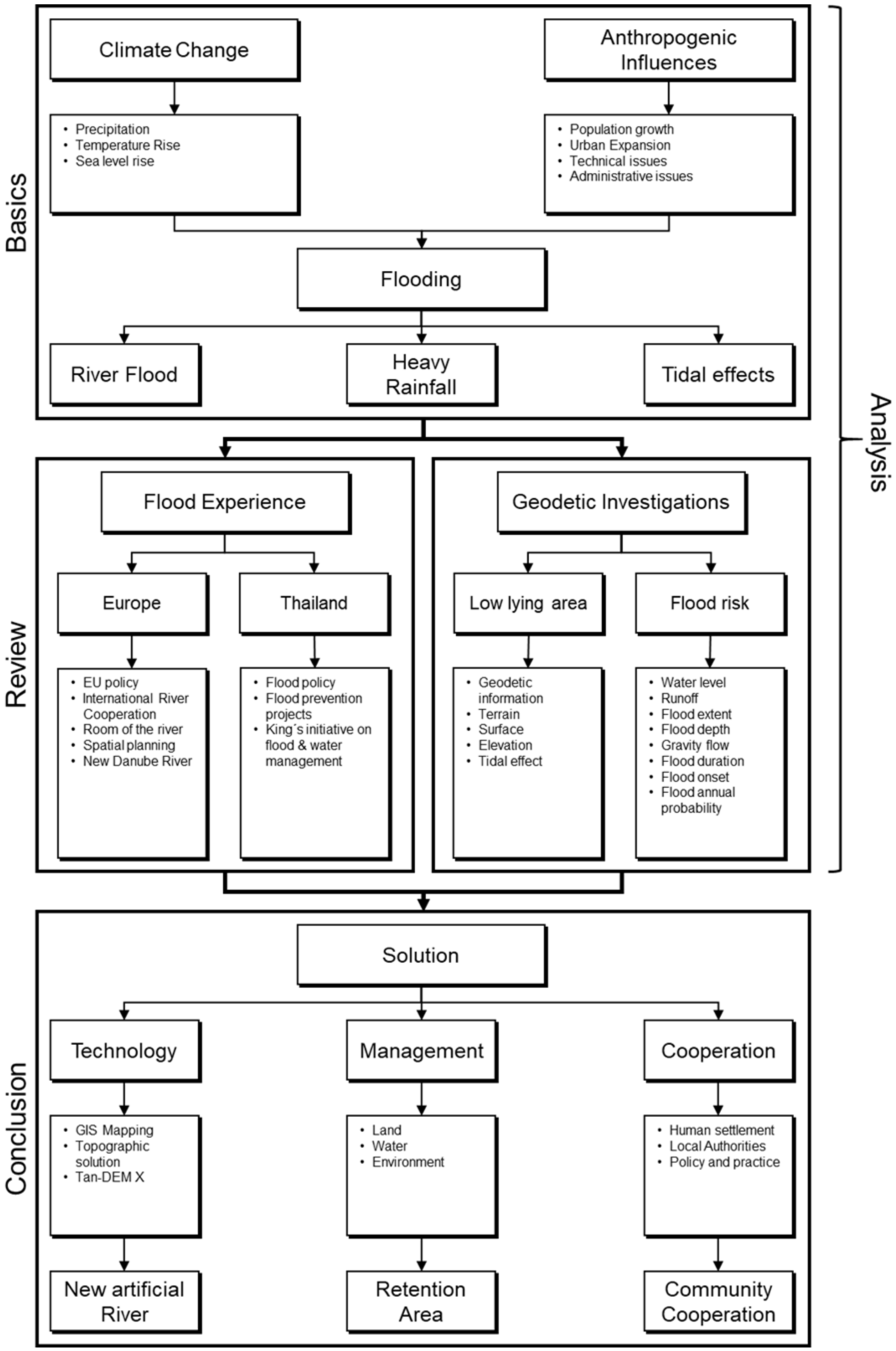


Figure 1.5 Research Methodology

1.6.1 Data Collection

The working process is divided into two main sections.

The first is the primary data collection regarding the cause of flooding in Thailand and European countries.

The data is gained by surveying and interviewing:

- Surveys of the flood management in Ayutthaya and the central area of Thailand and some of the example cases in European countries especially in Austria and Germany.

- Interviews divided into two main groups

    - Interviews with sampled local people in the flooded area along the Chao Phraya River.

    - Interviews with public and private sectors which are involved with Thai organizations and international and national experts which will be summarized mainly into the chapter three of human-made flood and flood management.

Secondly, the collection of secondary data involves the following:

- The characteristic of the flood issues and conditions of Thailand such as historical flooding, meteorological and tidal potential, human settlements, population growth, forest information, topography on earth observation satellite, etc.

- The flood prevention projects where the officials of the Thai government manage the flood risk management such as flood diversion from Thai Royal Irrigation Department, the Department of Public work Town and Country planning, The Highway Department, etc.

- The flood adaptation measures in Thailand, the national policy on flood management gained data from the Department of Water Resource. The forestation data was collected by the Thai Royal Forest Department, the population growth from national statistical offices, etc.

- The climate change and human-made flood issues reported by International organizations such as the IPCC, World Bank, UN-habitat, UNISDR, Munich-RE, GIZ and JICA, etc. are reviewed.

- The international collaboration on flood information from European countries and worldwide, for example the combination of the management of international rivers in Europe: the data will be gained by reviewing national and international flood policies of Europe such as the EU, ICPR, ICPER, ICPDR, Bafg, LfU Bavaria etc.

1.6.2 Data Analysis

After understanding the conditions of flooding and the methods of the flood managements, in terms of the challenges of the physical analysis, this research will use the Digital Elevation Models (DEM) for a spatial study. Therefore, the geoscience data of the area from the TerraSAR-X and Tan-DEM is loaded into the scientific program ArcGIS version 10.5.

(A) Spatial Analysis Tools and hydrological analysis is performed on ArcGIS Version 10.5 The result of the flow calculation provides the flow direction of potential flood water which will follow the lowest elevation.

(B) The design of the new alternative water drainage will follow the low areas while also avoiding human settlements and ecological forest.

(C) The plan of the new artificial river and the water retention areas will apply the supportive methods of the cooperation with the national flood management experiences in Europe.

Moreover, based on river capacity and flow analysis, one can calculate coarse estimations of discharge, velocity, inclination and mass movements of the cross section of rivers. The resulting values will integrate a specific of the new alternative water drainage, the velocity measurement and flow estimate will be useful the design in the new artificial river line.

As the result, the analysis of the data collection will present technique and the core guideline for the combination of water and land management by supporting the flood risk management through geodetic approaches with prevention and adaptation methods for humankind and natural resources.

1.7 Organization of the thesis

Chapter one of this thesis contains the introduction, motivation, aim of the research, state of the art and definition of the case study area, followed by the methodology of data collection and data analysis. The methodology uses geodetic approaches, concepts and definitions, surveying and mapping, remote sensing, Digital Elevation Models (DEM), Geographic information system (GIS) and water and land management.

Chapter two involves with the climate change scenarios, natural disasters and increasing of extreme events. The problems of flooding in Thailand, the usual annual average in the rain season, river flood, inundation flood and tide potential flood are the relevance of flood management. Climate change is one factor that causes floods and for solving these with a flood adaptation, the policy should be changed while awareness and cooperation is crucial.

In *chapter three* the anthropogenic interventions which influence the flood issues are mentioned and divided into three main factors such as technology, urbanization - human settlements and the administrative management factors.

Chapter four contains the flood management in the European environment and reviews many flood management projects starting with the European policy on flood management and the international cooperation of the Rhine river, spatial cooperation on the Elbe River, and the true multipurpose of sustainable flood protection in the Vienna Danube regulation.

Chapter five concerns the present situation and prospects along Chao Phraya River basin. There are many types of floods and influences of population growth that require to be considered. The areas of flood management of Thailand, past Thai experience with floods, relocation, water retention, and the flood diversion channel project of the Royal Irrigation department and land use planning from the department of Public works and Town & Country planning are areas of contention.

Chapter six contains the main work of geodetic investigation and interdisciplinary connections such as mapping, urban management, engineering projects, ecology and environmental management, geography and geo-information, planetology and hydrography. Importantly, the result of the design will be the need for a big scale measure and long-term planning functioning on realizing an artificial Chao Phraya River and natural water retention area on the cooperation measures.

Chapter seven provides the flood prevention and adaptation methods together with the conclusion and the outlook which concerns the purpose of flood management, possible further flood management and research.

In the consequence, the research’s purpose is to reduce flood risk, which is projected to be more severe in the future, by finding beneficial alternative solutions with balanced development and environmental benefits.

2 Possible Climate Change Impact

Climate change is possibly the main factor in causing more severe flooding. This chapter will describe the cause of climate change and how it contributes to natural disasters with the focus on flooding. The uncertain intensity of heavy rainfall, frequent monsoons (tropical storms), and the increase of the annual mean precipitation are examples of the extremely catastrophic risks that cause flooding. Additionally, sea level rise and tidal effects are projected to inundate local coastal and estuary areas. Climate change impacts and the planning for such issues should take into consideration future land use-planning and the implementing of adaptive measures (Schmidt-Thome et al., 2013). This research illustrates more information on the efforts of climate change scenario and climate change adaptation in Thailand.

2.1 A general overview of the 2011 floods situation in Thailand

Flood impact is one of the most significant natural disasters in the world. In 2011, Thailand encountered the most devastating flood in its history. The cost of the damage was estimated by the World Bank (Word Bank, 2011) to be 1.4 trillion baht (45.7 billion USD), which is 13 per cent of the country´s GDP. Particularly in November, more than 5.5 per cent of the total land area in the country flooded. (As mentioned in Chapter 1. Work Bank 2012, Munich RE 2012)

The floods covered a lot of land in especially extensive damage along the Chao Phraya River – the central plain area of Thailand. It also affected more than 13 million people from July to December. Figure 2.1 shows the record-high flooding from August to November (Munich RE, 2011).

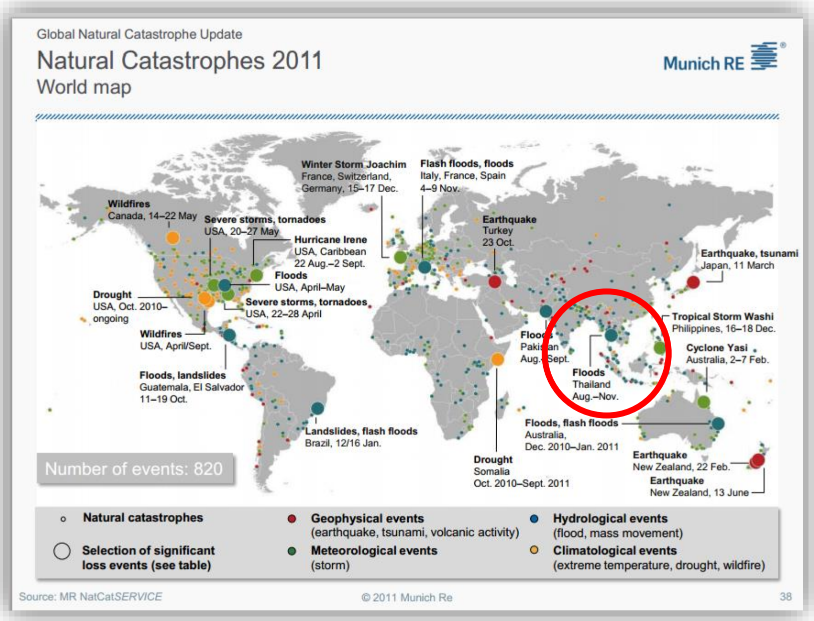


Figure 2.1 Natural catastrophes 2011 and hydrological flood event in Thailand
(Munich Re, 2011)

In Thailand, one-fifth of the country, including around 813 facilities, was affected by natural catastrophes such as floods and landslides in 2011. This was the same year as the hazardous earthquake that occurred in Japan (Table 2.1).

Table 2.1 The five largest natural catastrophes of 2011, ranked by overall losses (Munich Re, 2011)

Date	Country/Region	Event	Fatalities	Overall losses US$ m	Insured losses US$ m
11.3.2011	Japan	Earthquake, tsunami	15,840	210,000	35,000-40,000
1.8-15.11.2011	Thailand	Floods, landslides	813	40,000	10,000
22.2.2011	New Zealand	Earthquake	181	16,000	13,000
22-28.4.2011	USA	Severe storms/ tornadoes	350	15,000	7,300
22.8-2.9.2011	USA, Caribbean	Hurricane Irene	55	15,000	7,000

The estimate released by UNESCAP and UNISDR (2012) declared the natural catastrophe as the most severe in the country's history. The size of agriculture land damaged was around 11.2 million rai[6] (18,000 km^2).

Moreover, the flood event impacted the global industrial production by approximately 2.5 per cent, which severely impacted the global supply chains of automotive and electronics industries informed by Ministry of Economy, Trade and Industry, Japan (METI, 2015). The earthquake and flooding made Japanese investors in Thailand face economic consequences. Currently, the programme of recovery and reconstruction requires about THB 1.5 trillion (USD 50 billion) and at least five-year's period for completion (The World Bank, 2012).

2.1.1 Characteristic of the flood in 2011

(1) Rainfall (more details in topic of tropical storm; precipitation, and Chapter 5)

In average Thailand is hit by around 1.5 tropical storms or typhoons per year. However, between June and October 2011 Thailand had to face with four tropical storms and one typhoon. The tropical storms Hai ma (June), Nock-ten (July), Haitang (September) and Nalgae (September – October) as well as the typhoon Nesat (September) lead to historical damages in the Chao Phraya River basin (TMD, 2011).

The precipitation in the year 2011 exceeded the average rainfall in Thailand (1,522.4 mm) by almost 24 %. The average rainfall from the first January until the 27th November in 2011 set the record of 1,883 mm precipitation. This situation leads to a high flood water runoff and extensive inundation

[6] 625 Rai = 1km^2; (Rai / Thai Unit)

Basin mean monthly rainfall at the Chao Phraya River:

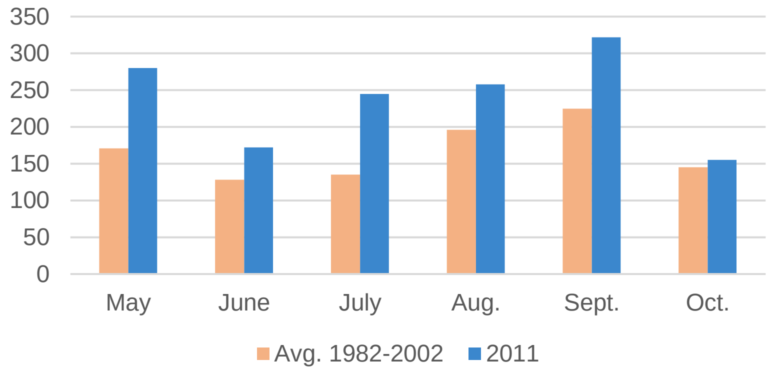


Figure 2.2 The average precipitation during the rainy season in Thailand

In the figure 2.2. the average precipitation per month is shown from the years 1982 to 2002 as well as from the year 2011. The rainy season occurs from May to October. September has the most rainfall.

(2) River discharge

The flood discharge hydrographs in figure 2.3 illustrate recorded devastating floods. The flood with the highest discharge of 5,451 m^3/s occurred in 2006 (JICA, 2013).

Flood discharge at Nakhon Sawan[7]

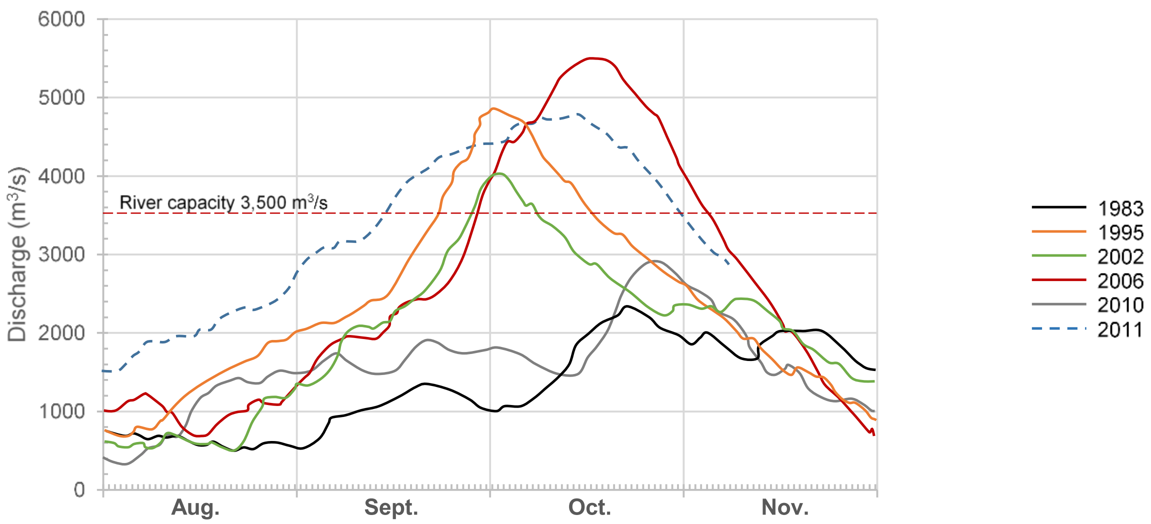


Figure 2.3 River capacity of the Chao Phraya River during the monsoon period

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[7] Data Source (Figure : "Reservoir Operation for Future Flood" by Oki Taikan, Institute of Industrial Science, The University of Tokyo, Presentation Material for 1st Joint Seminar of Integrated Water Resources Management on January 14, 2012. As cited in JICA (2013).

JICA in working cooperation with the Thai Royal Irrigation Dep. (RID) Thailand.

The hydrograph of the year 2011 presents a steady increase of the runoff during the flooding period. After the discharge became larger than the water capacity of 3,500 m^3/s in the river, it weakened the river dykes for about one and a half month before they became severely damaged at locations from Nakhon Sawan to Ayutthaya.

(3) Operation of Dam Reservoirs

Four major dams are located in the mountains north of the Chao Phraya River basin: the Bhumibol, Sirikit, Pasak Chonlasit and the Kwae Noi dam. Those dams can regulate their discharge and therefore compensate some amount of flood runoff. Before the flooding in 2011 occurred, the Bhumibol Dam already stored 7.5 billion m^3, the Sirikit Dam 4.7 billion m^3, the Pasak Chonlasit 0.8 billion m^3 and the Kwae Noi Dam 0.7 billion m^3 from May to October. Unfortunately, these four dams reached their maximum capacity by early October and were forced to discharge some of the stored water into downstream areas which made the flooding situation much more impacts.

2.1.2 History of catastrophic floods in Thailand.

Thailand has encountered disastrous floods in the past. According to the World Bank (2012), which reported that in 1942 the flood level in Ayutthaya reached 5.51 m and inundated the capital city of Bangkok for two months. Likewise, in 1983 a tropical storm (Kim) brought major damage and flooding into the country for five months, causing THB 6.6 billion in damage.

Moreover, storm surge typically involved with typically typhoons such as in the year 1989 when the coastal area was hit by Typhoon Gay and Typhoon Linda (1997).

Subsequently, the heavy rainfall in 1995 deluged the largest recorded area of 5,400 m^3. Even though the massive flood in 2011 was smaller, the affecting area was bigger than in 1995 and the impact it had on life and the cost of damage was more than 100 times the damage of 1983.

In 1998, the heavy rainfalls also caused flash floods in many areas.

Those unforeseen circumstances contributed to the 2011 floods marking on the magnitude of roughly a once in every 50 or 100-year flood event.

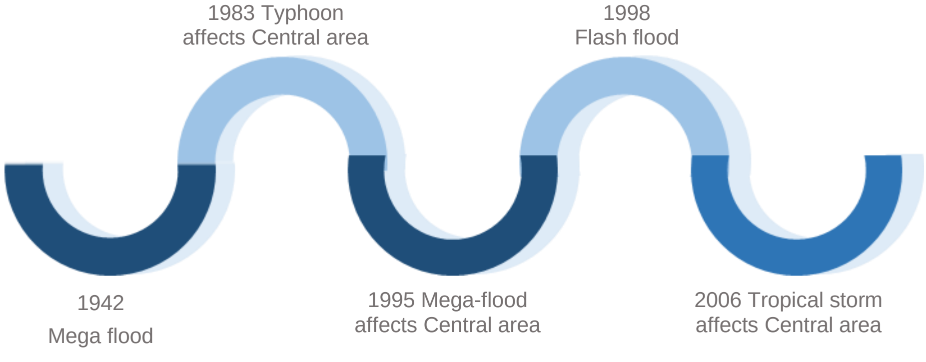


Figure 2.4 The historically catastrophic floods in Thailand

2.2 Climate change scenarios

Climate change is involved in a number of flood factors. Climate change is the most serious foreseeable threat to human development because it has the potential to undermine efforts to date (Bruce& Gavin, 2014). And it is less variable on the human timescale (ibid).

2.2.1 Climate change on global scale challenges

One issue of climate change on a global scale is the sea level rise. This research selected the topic of the rising sea level as an example for the flood situation in Thailand.

During the last 50 years, The National Aeronautics and Space Administration (NASA, 2010) reported that global warming is already influencing the changing climate. Climate induced changes have already been observed in all regions of the world, including sea level rise, more intense heavy storms, precipitation events, extended droughts and heat waves (ibid).

The planet's average surface temperature, the frequency of intense rain events and the sea level have risen and are trending upwards. For example, one of the events – the sea level – has risen between 1870 and 2000 by 1.7mm per year on average to a total of 221 mm (ibid).

Since 1993, NASA satellites have investigated that sea levels are accelerating to rise approximately 3 mm per year, for a total sea level rise of 48 mm between 1993 and 2009 (ibid).

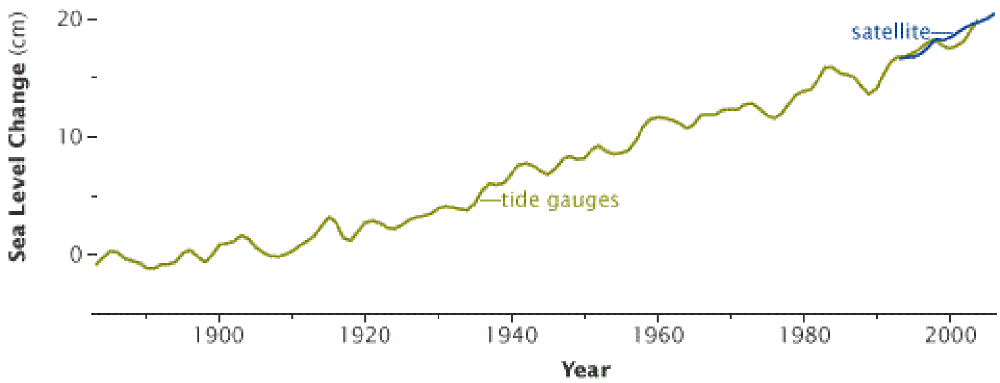


Figure 2.5 NASA satellites have illustrated that the sea levels are rising rapidly

Globally, the temperature in the year 2050 is project of change approximately by 0.8 to 2.6 °C, while the global sea level will rise around 5 to 32 cm (IPCC, 2007a).

The observation on the temperature rising across several decades relates to the changing on the large-scale hydrological cycle (IPCC, 2008 p.3). Climate model simulations for the 21st century is consistent with the increasing precipitation and the intensity in several regions, where, consequently, the heavy rainfall generated a high risk of flooding (ibid).

Thus, the negative impacts of worldwide climate change are projected to affect water systems like uncertain precipitation, river flows and water levels at river-basins. On the local scale, the risk from flooding hazards and human activity could expect to extend even more quickly with impacts to many vulnerable areas.

2.2.2 Climate change impacts on floods in Thailand

There are a lot of possible impacts from the climate change that are present in Thailand. Floods and droughts play important impacts to Thailand. However, this research will report the five main factors which are relevant to the flooding issues.

2.2.2.1 Precipitation (rainfalls) and tropical storm events

Thailand is located in the tropical Southeast Asian peninsula and is one of the rain forest area with well-watered plains. The climate seasons are based on two major wind systems, the north-east and south-west monsoons.

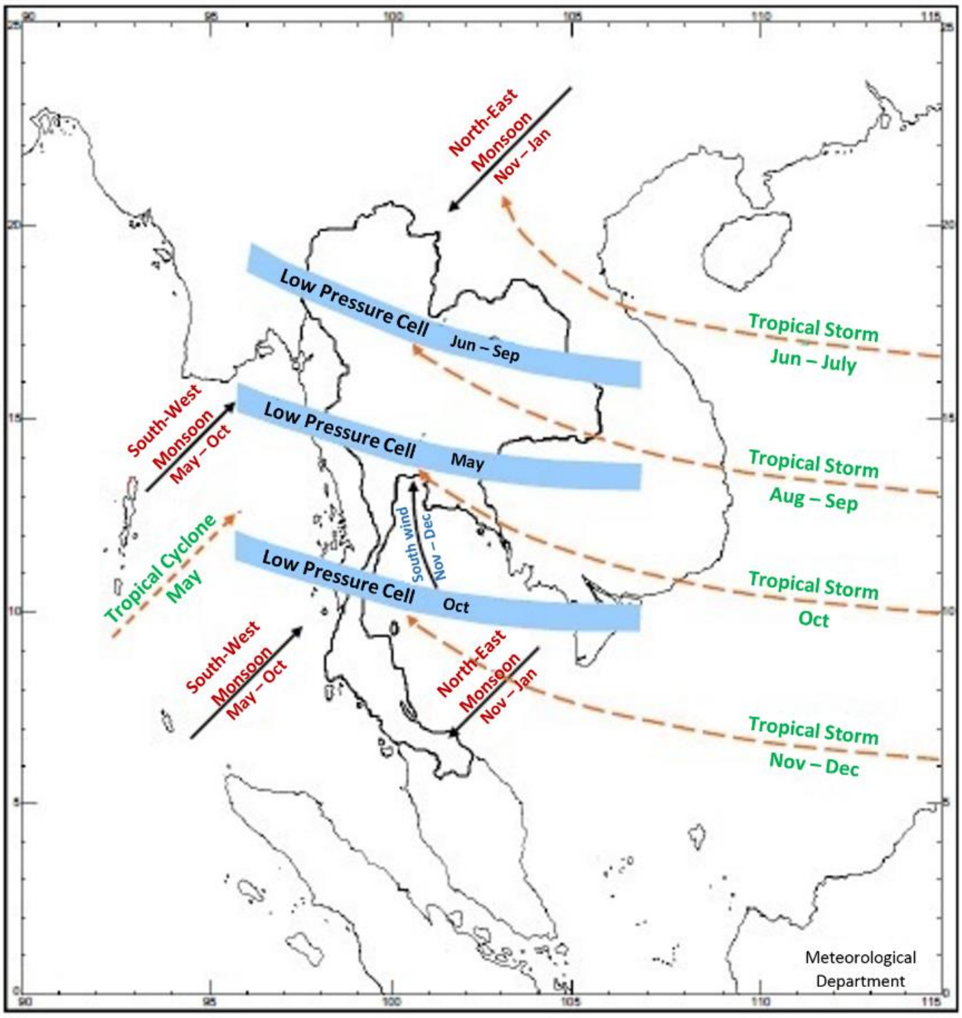


Figure 2.6 Position of low pressure cells (Tropical storm and Tropical cyclone in Thailand) (TMD, 2011)

Geographically, in the south of Thailand the rainy season lasts until December. The frequency of flood events during the wet season is defined by the south-west Monsoon (TMD, 2011).

The average trend of rainfalls has not changed significantly during the last 40 years:

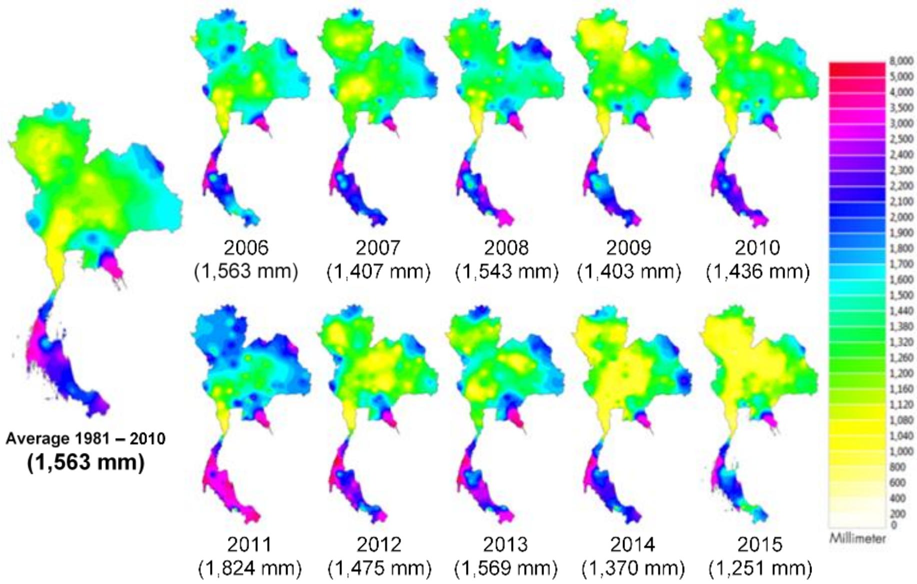


Figure 2.7 Average rainfall from 1981-2010 and rainfall information in year 2006-2015

The average rainfall trend in the last 10 years (During 2006-2015) increase unsteadily. Which implies that in some years there was more rainfall than other years while overall more rainfall occurred. In the year 2011, the rainfall of the country rose to 1,824 mm which caused massive flooding.

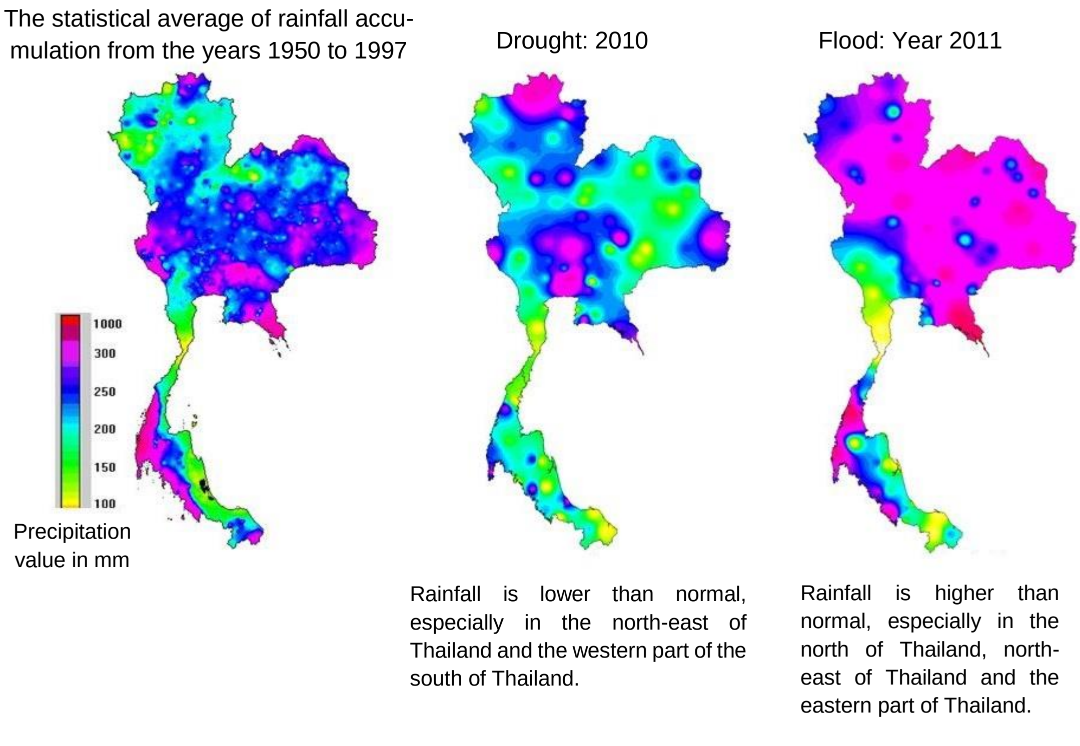


Figure 2.8 Rainfall accumulation in September (Hydro and Agro Informatics Institute, 2014)

Figure 2.8 indicates the rainfall accumulation data in the years 1950-1997. The central area of Thailand has been faced with alternating flooding and drought. The map of rainfall in 2010 provides drought data and in 2011 demonstrates in September of those years the peak of rainfall during the year regionally

In the year 2011, the pattern of precipitation was recorded with huge amount of rainfalls. Remarkably, the average precipitation in Thailand during the great flood in 2011 was at 1947.9 mm, which is 19% more precipitation than in the previous year. It was also 24% higher than the annual average of 1345.4 mm in previous years (TMD, 2011).

The annual rainy season in Thailand lasts between 3-5 months. It begins in the middle of May and ends at the end October.

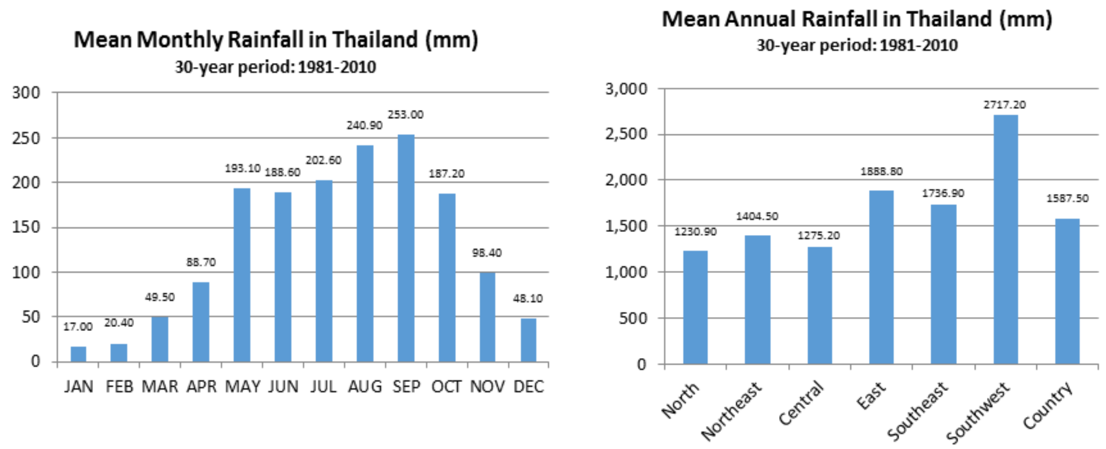


Figure 2.9 Rainfall in Thailand (TMD, 2011)

(Left) General Information of the Mean Monthly Rainfall in Thailand (mm) 30-years period: 1981-2010; (Right) Region area of Mean Annual Rainfall in Thailand (mm) 30-years period: 1981-2010

The tropical storm events are one of the influencing factors causing heavy rainfalls and flooding. A 59-year trend (1951-2010) shows that the extreme tropical cyclones occurred primarily in September and October.

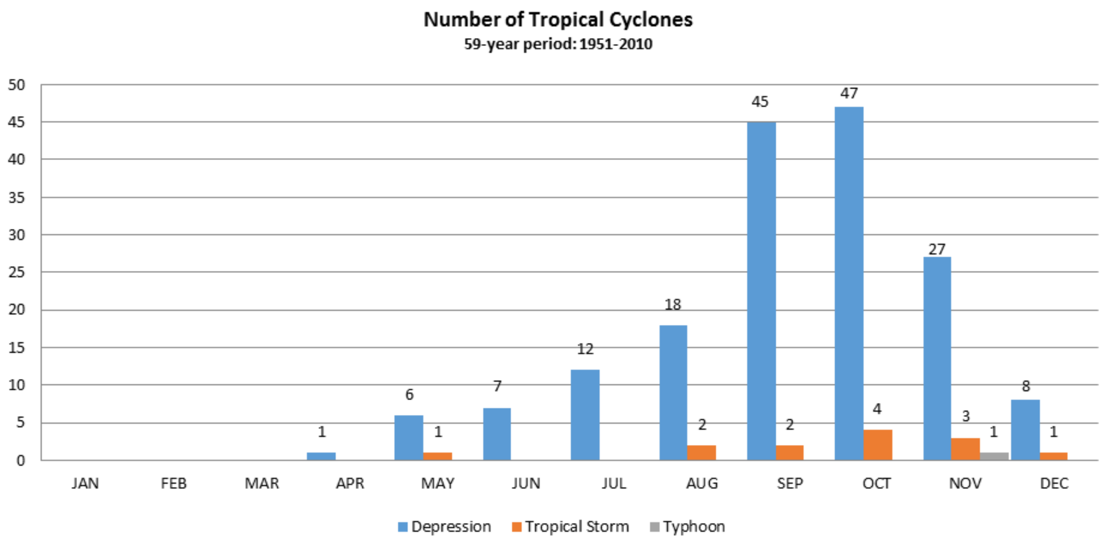


Figure 2.10 The number of the tropical storm in the 59 years (1951-2010)

Unexpectedly, in the year 2011, there were five tropical cyclones (TMD, 2011), which had some effects on the rainfall in Thailand.

The tropical storm NOCK-TEN hit Thailand hard on July 31st. During late September till early October the strength of southwest monsoon mostly affected upper Thailand.

The remnants of the tropical storm “HAITANG”, typhoon “NESAT” and “NALGAE” are associated with the high tide during the second half of October, which resulted in abundant rainfall with widely major flooding across upper Thailand, mainly in the lower northern and central parts of Thailand (ibid).

This extensive flooding in some areas such as Ayutthaya and Bangkok continued in the flood period of October to December in 2011. (*See further information in Appendix 1*)

- Haima (Green), June 24 - 26, 2011 / 285 mm of rain
- Nock-ten (Red), July 30 - August 3, 2011 / 451 mm of rain
- Haitang (Violet), September 30 - October 1, 2011 / 164 mm of rain
- Nesat (Light Blue), September 30 - October 1, 2011 / 265 mm of rain
- Nalgae (Brown), October 5 - 6, 2011 / 222 mm of rain

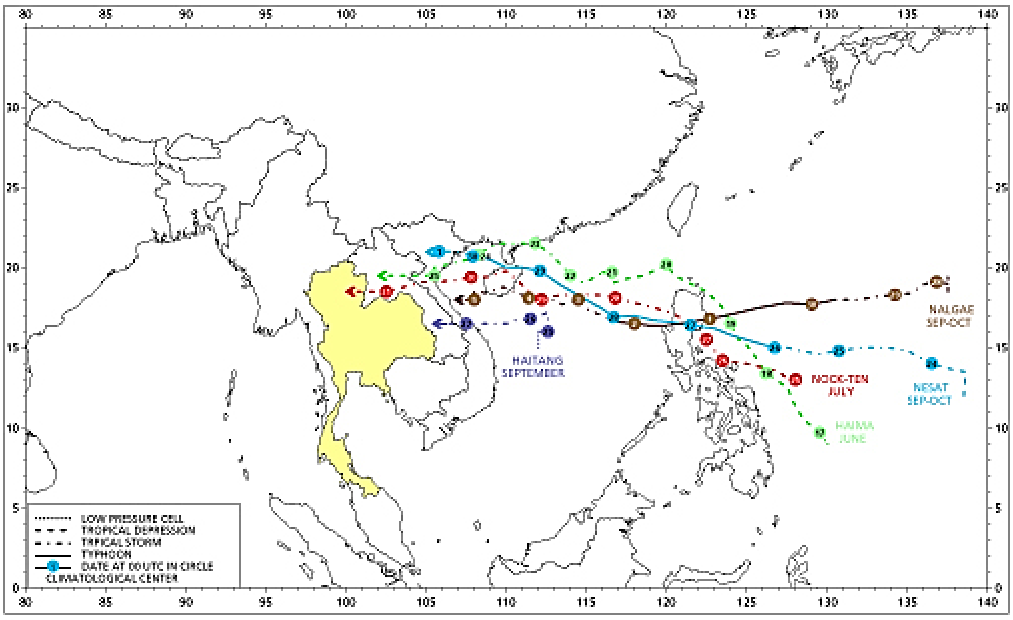


Figure 2.11 Track of tropical cyclone affecting Thailand in 2011 (TMD, 2011)

2.2.2.2 Temperature rise

In Thailand, the seasonal temperature rise begins in early January when a high pressure from China is influencing the northern area and north-eastern part of Thailand around the mountains. The most extreme differences between cold and warm days mostly occur in the area of the north-eastern region. During summer in April, the temperature increases to a maximum of 40.7 °C in the north-eastern part (Satuek, Burirum province), as it was on 18 April, 2011 (TMD, 2011).

According to the Environmental Institution Team in Thailand (Limsakul et. al., 2011), the number of hot days increased by 3.4 days/decade while the number of hot nights increased by 3.5 days/decade in the period from 1970 to 2006. On the opposite, the number of cold days decreased at a rate of -1.9 days/decade while cold nights decreased by -3.0 days/decade. The average seems to be consistent with the global trend, with a lot of widespread significant warming trends in the past decades.

Thus, the changing temperature in Thailand is expected to lead to an increasing risk with the changing climate and leading to increased vulnerability of the country.

2.2.2.3 Sea level rise

According to the Intergovernmental Panel on Climate Change (IPCC 2007a) the rise of the sea level is consistent with global warming. The global average sea level rose at an average rate of 1.8 mm per year over 1961 to 2003 and at an average rate of about 3.1 mm per year from 1993 to 2003. Also, following year more research on global warming indicates, the sea level rise on global scale has an average 3.2 mm per year in the period from 1993 to 2010. The consequences of a rise of the sea level are abundant; millions of people will be subjected to floods, coastal ecosystems will be destroyed, and the sea level rise will exacerbate freshwater constraints due to salinization of estuaries and groundwater supplies.

“Predicting future sea level change requires an understanding of the contribution process at reginal and local levels” (Fenoglio-Marc, 2015) *“Sea level is not uniform and some regions will be more affected than others. It can possibly exacerbate the effect of factor, such as flooding and ground subsidence”* (ibid).

Information from the Southeast Asia START Regional Center study in 2010 provided more detailed data on local scale of the Chao Phraya River basin.

In summary, sea level rise along the coast of the Gulf of Thailand during the next 20 years (2010-2029) could be in the range of 5 to 10 cm, where the Inner Gulf of Thailand would be most severe, followed by the Southern East Coast and the Eastern Coast of Thailand. The trend of sea level rise will be more severe in the following two decades period (2030-2049), which change in sea level could be higher than current condition by 10-20 cm and the level of severity of area will remain. It should also be noted that the change in sea level will vary from month to month due the effect of monsoon season.

The predicted data for the future is as follows:

The study predicted a 10 % increase in annual precipitation in the Chao Phraya River Basin for the period from 2045 to 2065, The prediction of the next 20 years sea level rise along the eastern Gulf of Thailand will reach 5 -10 cm and in 2030-2049 could be more severe by 10-20 cm the inner the Gulf of Thailand.

Table 2.2 The relative sea level rise in Thailand (The Southeast Asia START Regional Center, 2010)

Year (in Thailand)	**Relative Sea-Level Rise**	**The Estimated Maximum**
2010 to 2029 2030 to 2049	9.4 cm 20.0 cm	17.0 cm 28.9 cm

By contrast, there is still some debate amongst the scientific community how the increased sea levels influence coastal erosion and shifting clay soil around the Gulf of Thailand.

According to the group of joint Thailand-Europe research (2012) a long-term sea level rising rate around the West and North coast can be clearly detected since 1940 at around 3 to 4 mm per year. The rapid increases on these rates were detected by satellite altimetry (1993-2008) with no evidence of sea level fall. This rise of the sea level is possibly being amplified by land subsidence or land submerge and plate downfall in the region. Through traditional ground survey it was found out that subsiding swifts at rates greater than 15 mm per year such as Bangkok City is presently sinking at an average rate of 5-10 cm per year (AIT, 1981) and Samutprakan port city bank where is presently located the international Airport Suwannabhumi. Those areas led to detached houses along the river and the Bangkok metropolitan is gradually immersing by subsiding rates at 10 mm per year. Thus, this reveals the alarming findings that could change all currently adopted future scenarios of sinking Bangkok while many cities are surrounded by extremely floods, coastal erosion, salt water intrusion and environmental degradation.

2.2.2.4 Land submersion

"The most pessimistic experts are afraid part of Thailand's capital will be submerged by 2030".

Time Magazine: 2011, July 21st Thursday.

The problem of Thailand is not only the sea level rising, but also land submersion, which is one of the most significant issues. The submerged areas are mostly found along the sea shore on the central part of Thailand, especially the Bangkok metropolitan and peri-urban area.

One of the interviewee on Thai geodesy engineers on their working record of land subsidence during the years 1978 to 2008 found, that in 30 years the Bangkok metropolitan and neighboring area have been sinking for 1 m, with a cumulative submersion average of 2-3 cm per year.

Figure 2.12 Data collection on land submersion and sea level rising relatively

Interviewee: Col. Chaiwat PROMTHONG
Director of geodesy division, Royal Thai Surveying Department. Thailand.
(2014, December 1st).

Providing information on Land subsidence of Bangkok (data collection since 1979)

Moreover, the data from the Department of Ground Water Resources (DGR, 2012) reported that the land subsidence is related to the quantity of the consumed ground water. Currently, the drilling of underground water in Thailand is controlled using local municipality consideration under the control of law and regulation; Ground water Act[8].

2.2.2.5 Coastal erosion

The coastal area is characterized by natural geological landscapes such as sandy beaches and dunes, coastal wetland, rocky coasts, cliff coasts and islands (DMR, 2011).

The coastal zone of Thailand is 2,420 km and consists of 23 provinces along the Gulf of Thailand and the Andaman sea coast. This area is highly populated with approximately 12 million people (ibid).

[8] Thailand (Bangkok) Ground water Act (1972, 1992, 2003)

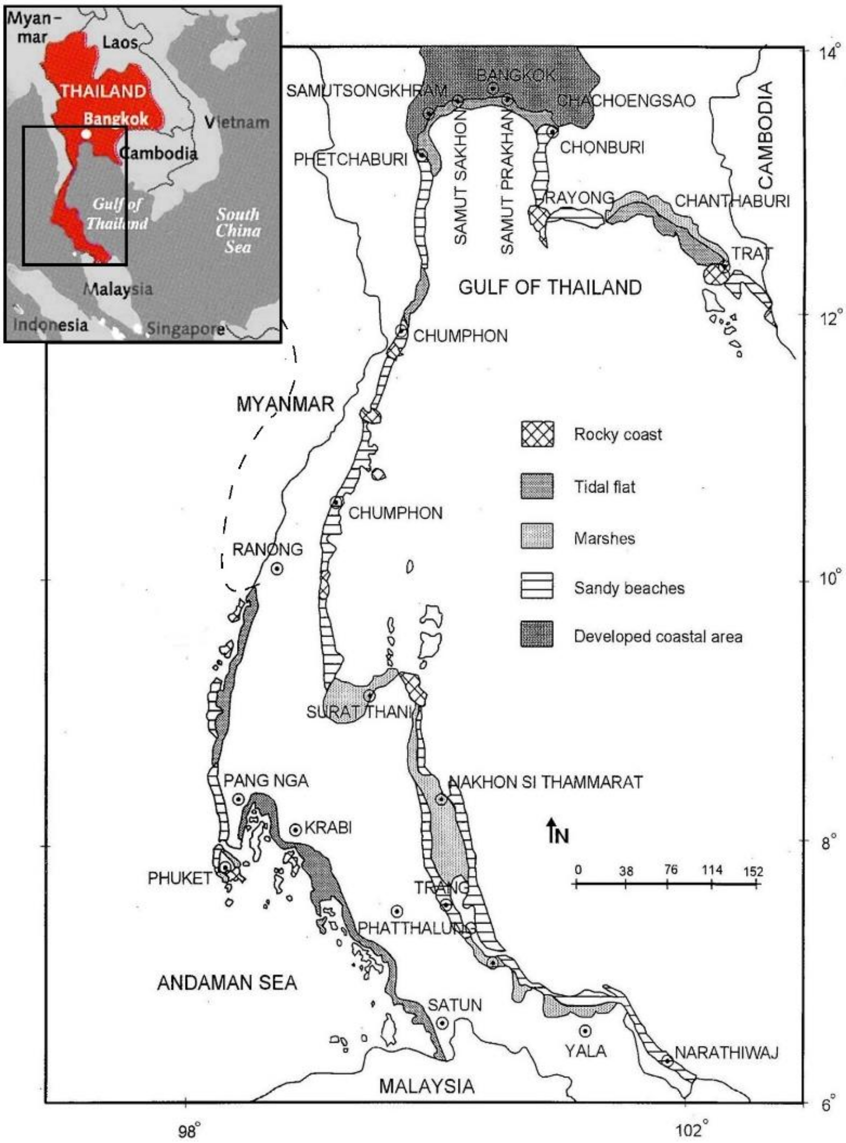


Figure 2.13 Coastal area of Thailand (DMR, 2011)

Thailand is confronting challenges and coastal problems from natural events and human activities as the multiple consequence of urbanization and industrial and tourism development (Siripong, A., 2010; DMCR, 2011 and Shott, 2012).

The natural events such as sea level rise and tidal fluctuation are accelerating coastal erosion, land submersion and inundated flooding. For example, in the tidal flat area of the Central region, the Hydrographic Department of the Royal Thai Navy (RTN, 2011) mentioned that in case of great flood 2011 Thailand faced with natural former year of El Nino (less rainfall) and human factor effects. From that during the high tide, water can reverse and flow upstream into the river where it influences coastal flooding and indurated flooding.

The Royal Irrigation Department (RID, 2014) reported more frequent tides, which have propagated to 120 km in the Bangsai District, Ayutthaya province. Having high estuary tides causes difficulties in draining the water from the lower Chao Phraya River basin and thus causes floods in the basin.

"Numerous times, from the estuary shoreline the sea high tide has come into Chao Phraya River where it affected the Ayutthaya province in the main land. Therefore, the Ayutthaya Irrigation division had to use fresh water from the main river land to push the salt water from the sea back into the ocean. In some events, these phenomena are one of the causes of inundated flooding in Ayutthaya"

Interviewee: Mr. Montree PITINANON
Director of Operation and Maintenance Project
Ayutthaya province, Irrigation Department. Thailand
Manager local newspaper (2012, February 7th)

This brings not only problems of inundated flooding but also problems of salt intrusion and contaminated salinization, which will impact the consumption of fresh water. The rising acidity can have significant impacts on ecological coastal systems.

Likewise, the eroded coastal areas in Thailand have rapidly changed in the last two decades by human activity such as the growth of the population and the marine industry, the intensified development of tourism such as hotels and highlight buildings, roads construction and overexploitation of resources along the coastline.

For instance, the construction of roads or railways that are parallel to the coast causes trouble in the hinterlands. These roads and railways do not have proper built drainage ways which prevents water from spilling into the sea. This also adds to more flood problems due to the accumulation of sediment deposition. In case of another flood in the future, the sediment accumulated in the drainage systems from the previous flooding makes it difficult for the water to flow back into the Gulf of Thailand.

From this point of view, the natural coastal erosion combined with human activities are causing flooding, which will continue to be the most critical challenge for mitigation and adaptation measures under the condition of the global climate change.

2.3 Climate change adaptation efforts in Thailand

Currently, adaptation to climate change in Thailand is top priority as a national responsibility. In cooperation between the Office of National Resources and Environmental Policy and Planning (ONEP) and Ministry of Natural Resources and Environment (MoNRE), the Climate Change Master Plan (2013 – 2050) is in development. This climate change framework includes integrated policies and action plans.

According to International Research Network for Low Carbon Societies and Low Carbon Asia Research Network (LCS-RNet, 2015) reported that the objective is to support climate change preparedness initiatives with the focal point on main efforts of economic and socio-cultural contexts and importantly sufficient economics philosophy.

The Chiaipattana Foundation (2017) reported that the “Sufficiency Economy” emphasizes the middle way as an overriding principle which was conducted by Thai people at all levels; from the family to the community and the country. The Office of Natural Resources & Environmental Policy and Planning, Thailand (ONEP, 2015) presented that a suitable climate change adaptation can be achieved by following the guidance of the Philosophy of Sufficiency Economy, bestowed by his majesty King Bhumibol Adulyadej.

The policy of climate change adaptation in the future is mostly concerning water, land and the environment as concluded in the following (ibid):

- To promote the Integrated Water Resource Management (IWRM) in practices by maintaining the water resources with mitigated floods and droughts.
- To apply the new theory on agriculture and appropriate land management into well-allocated land and water resources in order to support economic diversification at the household level.
- To increase the building knowledge, capacity and technological support such as early warning systems, development of databases, models and technology including more systematic climate risk assessment for the local communities.
- To enhance awareness, coordination and adaptive capacity for the specific risk-disaster prone areas so as to reduce the population’s vulnerability to climate risk from the extreme weather events.
- To grow the national forest coverage to 40 per cent as well as to prevent a decrease in biodiversity, integrated marine conservation, protect coastal erosion on coastal rehabilitation plans and ecological restoration in protected areas with well-practiced community participation and appropriate adaptive capacity.

To sum it up, the changing of the climate, natural disasters and impacts are still continuously increasing worldwide. Having the capacities to support major strategies and ensure well-equipped communities, will probably support the decreasing of the risks and the climate vulnerability in Thailand.

2.4 Chapter Summary

Climate is one cause to the interplay of a number of flood factors. Climate is, in a sense, weather averaged over a long period of time; as such, it is less variable on the human timescale. While climate change may bring more impact on flood by increasing heavy rainfall and monsoons, coastal erosion and sea level rising. These factors are related to human activities in the regional and global scale. Thus, climate change is likely to result in increasing demand for management on flood risk prevention and adaptation measure in the future.

3 Actual anthropogenic interventions

According to UN-HABITAT (2013 p.11) the *“anthropogenic change is already so great that we are in serious danger of doing permanent damage to the global environment.”* Rapidly urbanizing areas is one of the main reasons causing heavily excessive flooding around the world.

This chapter will present the influence of human activities on tremendous disasters by pointing out the influences in the Thai context. Reasons for man-made floods are summarized in the following seven topics (3.1- 3.7).

3.1 The rapid growth and development in country

Thailand is one obvious example for the rapid growth of cities in the central region. The population growth and the urban development are the primary challenge for more hazard floods impacts. Without control, these will be an obstacle for managing floods in business investment areas. For example, transforming agricultural farmland into residential areas and industrial estates, which were originally located in the black mash or wetlands caused problems when the government and the industry promoted investing and developing the potential flood plain area (METI, 2012 p.323). The wetland areas have been used as natural water storage or ground water conservation in central area of Thailand. Despite the government’s disregard of the risks (Meehan, 2012) the area was new-built located, where in the past a seasonal flood was efficient use of cultivated areas, today the flood causes mostly negative impacts on the group of people living or doing business in the central plain area.

3.1.1 Human settlement

Without doubt, the natural settlement of the communities from several decades ago was mainly about easy water access and the location of the number of housing along the main river in Thailand. Geographically, the central region of Thailand confronts with a regular flood season and people felt blessed and were used to these seasons and having floods from the free-running river in their lives. This lifestyle was adapted to the water, the living conditions were suitable and flooding as a benefit by using the flood as a natural fertilizer for the agricultural land in the flooding season.

3.1.1.1 Histories of housing characteristics and public facilities change

Throughout history, it is hard to deny that massive floods caused severe damages in Thailand. Some of the main reasons of those damages are the changes in housing characteristics and facility services in terms of the urban and rural development.

In the past, local people who were living in river areas, applied traditional materials for their housing and facilities construction. The big scale of the goods transportation was done by vehicles on the river, which did not block the natural water drainages like nowadays by creating main road construction networks.

Housing construction's design and local materials were well adapted for a life with seasonal flooding. For example, the houses were built with high basements so that the water could pass underneath the house and the wind can flow from literally every direction into the house. This was of advantage for people who were accommodated in the house not to get hot and humid during summer time.

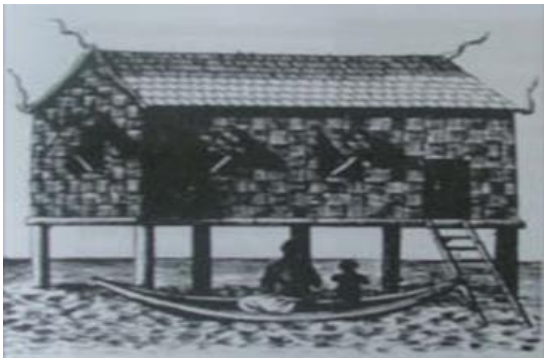
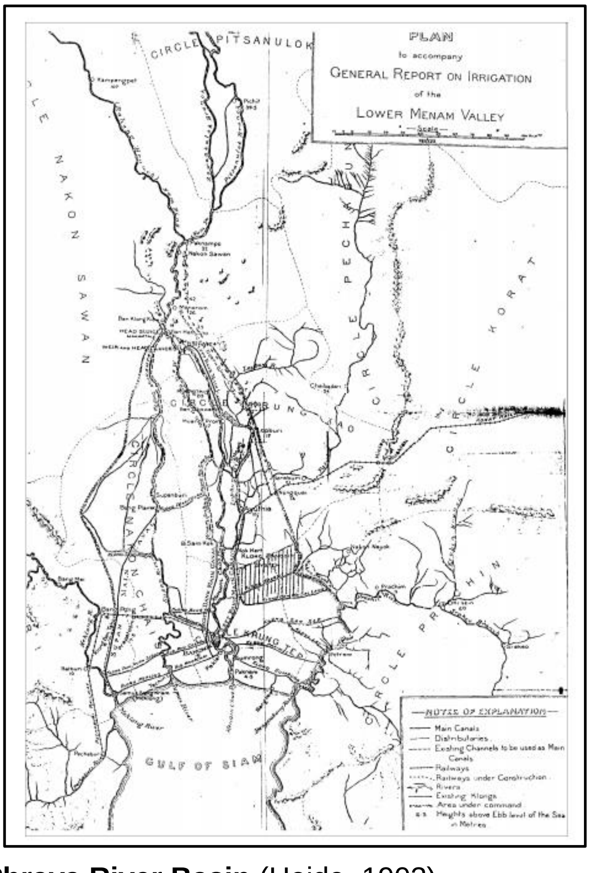


Figure 3.1 Siamese living style (the simple and functional forms for tropical living) (Thai Encyclopedia, 2015)

Moreover, the residents around the sub-urban areas could travel normally, get in touch with each other or trade in the capital city Bangkok by boat because of the location. This was the main reason for people in the past to prefer living along the river.



Map 3.1 Lower Chao Phraya River Basin (Heide, 1903)

Roachanakanan (2014) mentioned that since the early 19th century urban development in many cities of Thailand (e.g. Bangkok and Phuket) and neighbouring countries (e.g. Singapore) has transformed with western influences. Likewise, building up the transport system began from the northern part of Thailand by railway development and logging industry.

Also, the irrigation project in Thailand initiated by King Rama V. was developed which was focusing on the adoption of the water management policies with the aim of increasing the *rice production.* That earned the main income of Siam Kingdom (Thailand) during that time.

And in 1910, Homann van der Heide[9], a Dutch engineer, proposed a network of irrigation canals on the central plain area. At that time, it is described that in the north and the east of Bangkok no settlement was present. Even Bangkok itself was only 12 km long in total.

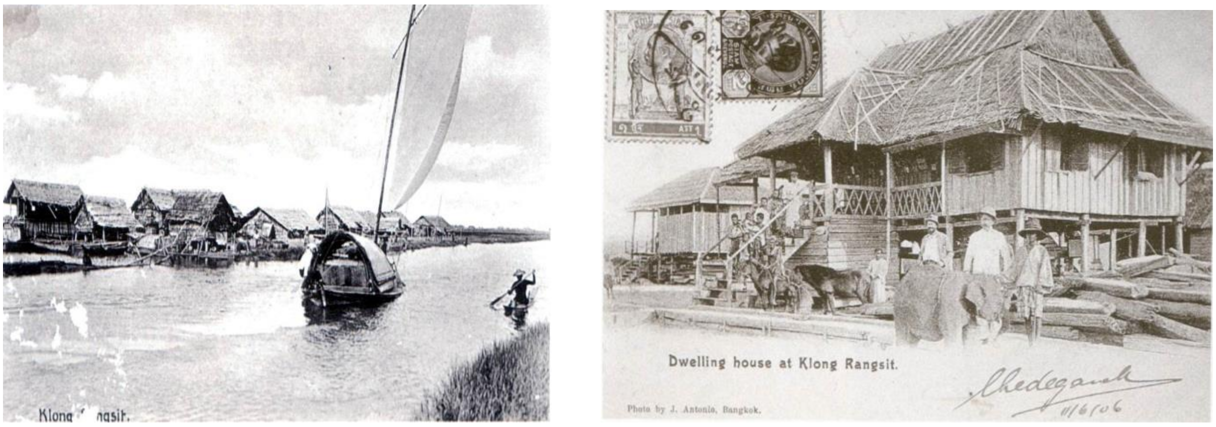


Figure 3.2 Historical dwelling along the cannels

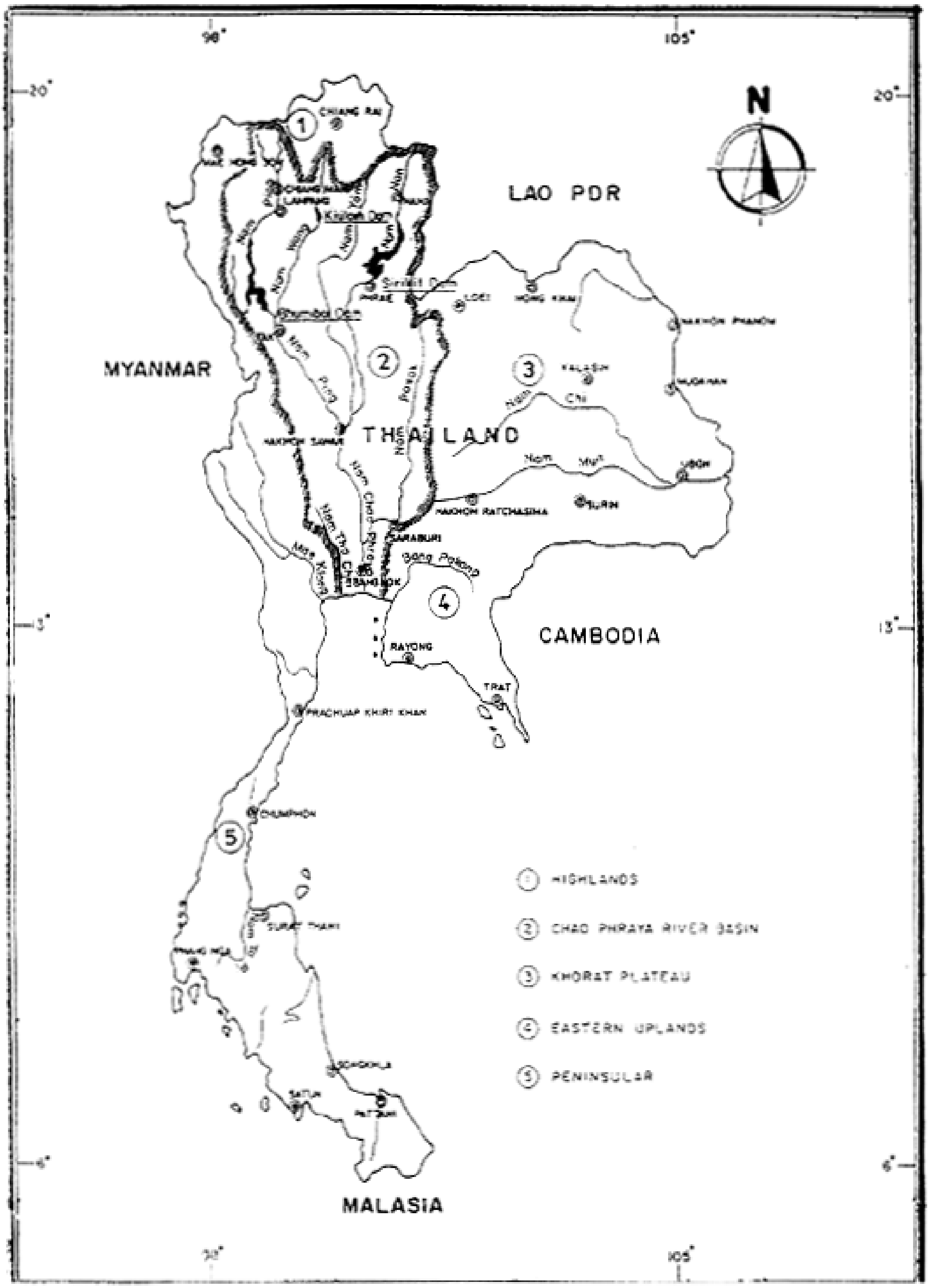
(Left) King Rama V opened the Rangsit Irrigation project on 18th November 1896 (Songsiri, W., 2016). (Right) The Rangsit area located on north-east of Bangkok was a popular area for Western people in the 1900s for building vacation houses (Bangkok Post, 2009).

Figure 3.3 100 years ago in Bangkok and transportation (Thai Rath, 2017)

[9] (Homann, 1902) The Thai Royal has hired Mr. Heide (Dutch irrigation engineer) to operate the irrigation in Thailand (in 2445 B.E) and appointed him into the position of the Thai civil servant of the first director of the "canal" department on June 13, 1902 where the tasks of working on the creation, observation and maintenance of the canalization systems in Thailand was waiting (RID, 2015).

Since that period of time, only a few traditional floating houses were settled, and even those changed to live in the city where the families are close to roads and railway routes.

Besides, the changing of the traditional housing and settlement are the beginning of the appearance of more severe floods in the central region of Thailand. Furthermore, the growing transportation system is causing many negative aspects, for example the deterioration of the natural cannels and water retention environment etc. Also, there are still problems related to unauthorized land settlements along rivers, such as the settlements along the Chao Phraya River.



Map 3.2 Thailand map and Upper – Lower Chao Phraya Basin (Heide, 1903)

3.1.1.2 The present situation for living with water

From survey (Housing and Transportation: Central region, Thailand)

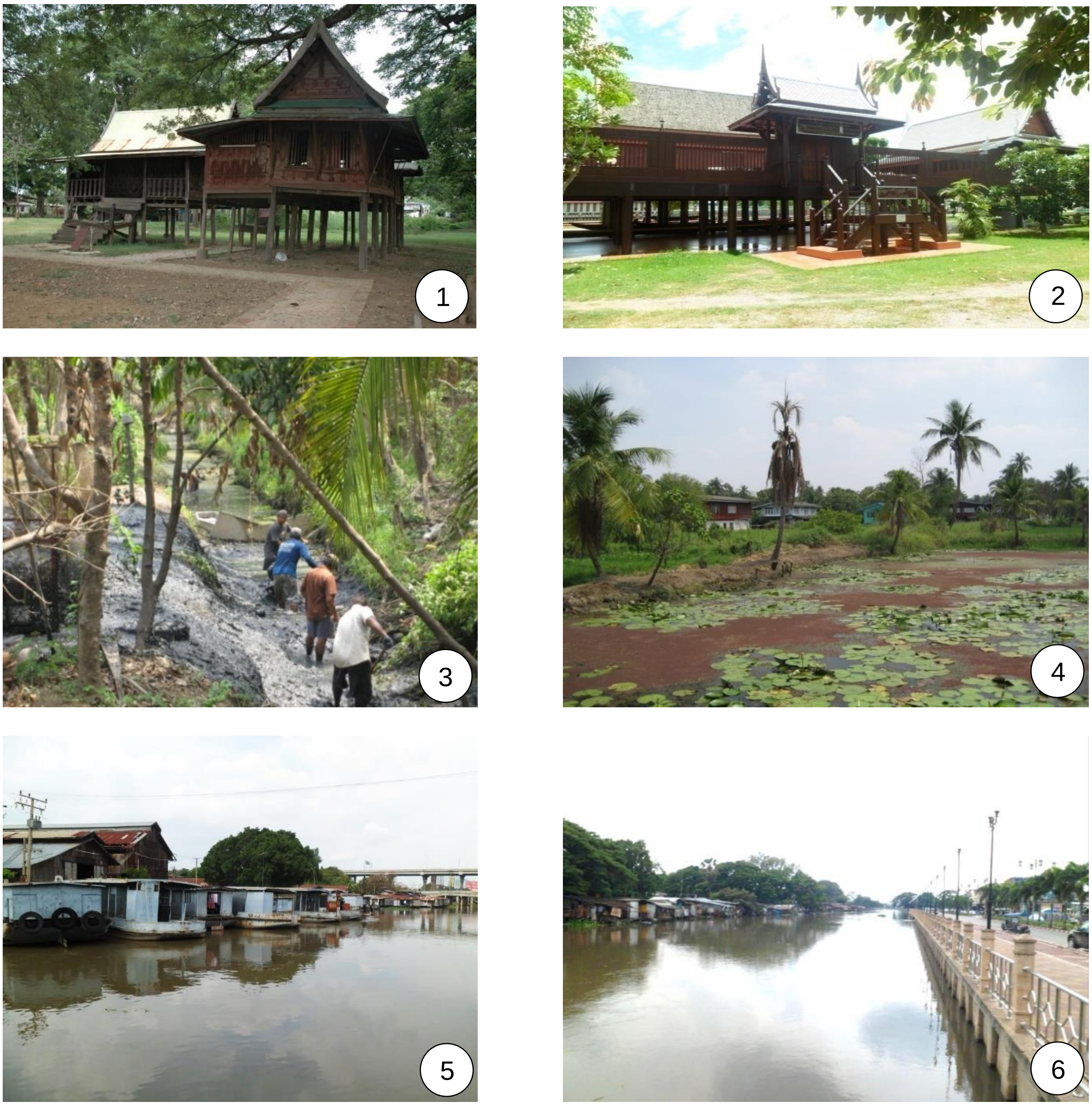


Figure 3.4 Living with water (Author, 2013)

Ayutthaya (1), Ampawa (2), Kokret (3, 4), Rangsit floating (water) community (5, 6)

At present time, boats or floating houses for living along the river can be rarely seen as often as in the past. Although there are still some renovation programs trying to bring back the traditional housing style, but communities' life in the waterfront areas are settled for some services for tourist purposes not for cooperative culture. It supports bringing back good economic aspects, including the logistic transportation of sand and construction materials, which has developed for the commerce in the capital (located in the mouth of the river, where many essential harbors are located). However, the new settlement is changing not only along the river but also in areas near by the main sources of transportation or the main motorway, since convenient infrastructures such as road construction has become more used than before. The transportation of good by land begin more focused in developing than in the past.

Currently, a community in a linear settlement along the river spreads chaotically, for example by people settling along the main street or nearby the central area of the city. Severely, by the floodplain development, increasing accumulation of population and wealth in flood-prone areas, humans have been driven to occupy unsafe areas (e.g., informal settlements on flood plains), thereby increasing the potential loss (Ramesh, 2013).

From my point of view, learning the historical knowledge from ancestors is crucial for developing new infrastructures to adjust the living to the required changes. Concerning flood impacts, the planning has to carefully consider the impacts of changes on local communities who are living with the water. One measure of controlling settlements is formal zoning. Furthermore, the management of formal and informal settlements along the rivers play a significant role on urban development and guided land-use planning to minimize flood impacts. Designing urban and rural areas with restoration or development on housing and facilities including transportation need to have clear versions and proper directions of planning for flood adaptation in the future.

3.1.2 Urban expansion

Inevitably, the rate of demographic and economic growth has dramatically increased in the cities and accelerated migration around the world. The shifts have transformed countries, making cities and urban centers the dominant habitats of humankind.

In 2011, the global population reached the amount of 7 billion, and it is projected to climb to over 9 billion by 2050 (UNFPA, 2013).

In Thailand, this expansion can be seen in structure developments of urban settlements in natural flood prone areas. In the central plain area where the massive flood in 2011 occurred, urban sprawl became chaotic and could not be controlled around the capital city Bangkok, as city planners and urban designers failed with considering the three functions (UNFPA, 2013) on planning:

- Urban growth boundary
- Utility service areas
- Agricultural and natural resource lands

Highly efficient agricultural farmland and horticulture has been changed to peri-urban areas. There were also many canals along those areas, which had an important role in some cases of flooding by storing the flood water.

Hereby, the problem of urban sprawl can also represent a flood risk around the outskirts of Bangkok, nearby the Chao Phraya river bank and the harbor city. This additionally leads to low quality of life and many people have to encounter water and air pollution (Tipyasotorn, 2008).

According to ICAADE conference in Thailand, one participant; Benjamin Casper, *mentioned that "Delta cities are crucial regions of adaption. They are contested spaces of a growing urban* *population and urban space, while climate change and ground-subsidence increase the potential damage and thereby the necessity to transform* (Casper, 2016). Bangkok in the Chao Phraya Delta consists of thousands of kilometers of anthropogenic waterways. The waterways form a complementary entity to the terrestrial infrastructure. The spatial frame for understanding the social-ecological system of *khlong* (waterway) is the waterscape, consisting of the canal and the natural or planned flooded adjacent spaces” (ibid).

For example, Bangkok and cities such as Nonthaburi, Pathom thani and Ayutthaya had many canals for transportation, whereas nowadays, many of those canals have been changed into plain land for the development of buildings.

Moreover, the city consumes a great amount of energy and lacks green areas and natural water retention caused by residential areas that are located in flood plain zones. All these negative aspects were caused by the growth of the population and the urban expansion, without the ability of effective controlling by setting a suitable growth rate for the infrastructure, housing and the city population.

The city expanded as more people moved into the town. Those people are emigrating mostly from rural areas to the urban area, for purposes such as job opportunities and a better standard of living. Those reasons also cause negative impacts on local and urban life styles and the characteristic of a habitable environment for migrants, which results from the conflict of the urbanization with the agriculture and industrial areas, for example the conflicts between the water ways and roads.

Thus, fast-growing urbanization has resulted in a loss of natural water resource areas due to rapid urban expansion. The American Planning Association (2015) mentioned that one option to tackle these problems are cities with smart growth concepts, which have an urban planning and transportation theory that concentrates on compact growth in order to enable people to move into urban center and to avoid sprawl.

As concluding remark for future, the new city design should be compact, transit-oriented, walkable and bicycle-friendly, with a land use which is including neighborhood schools, complete streets and mixed-use development with a range of housing choices. The city itself should be well-organized and should have a capacity knowledge management for communities on how to live naturally, safe and in harmony with the environment. Ultimately, the land zones should plan human settlements with a limited number of housings and well controlled urban sprawl by keeping the preparation for flood mitigation and adaptation in practice.

3.2 Deforestation and inadequate ecosystems in upstream and downstream areas

FAO (2007) Forest areas are the best land cover to maximize the water area. In these areas, the regulated seasonally flows ensure high water quality, while the forested catchments supply a high proportion of the water for household, agricultural, industrial and ecological consumption in both upstream and downstream areas.

FAO (2015, p.14) The forest areas of the world still continue to decrease over the last 25 years (1990 – 2015), however, it only decreased by 3.1 percent which is a 50 % slower rate as the years before. This enhancement was achieved mainly by supporting the forest area expansion, while the human population grew continuously by about 37 %.

Deforestation is also primarily a concern of Thailand (UNFCCC, 2016). In the year 2011, one of the floods with the most impacts covered the northern part and the central region of Thailand and was caused by the continuous reduction of forest land.

In Thailand, forest cover has reduced from 53.5% in 1961 to 31.6% in 2014 as a result of population growth, infrastructure development, agricultural expansion, illegal logging and uncontrolled forest fires. On average, the annual deforestation rate was estimated at 0.6% or 140,000 hectares[10] per year, from 1973 to 2014 (ibid).

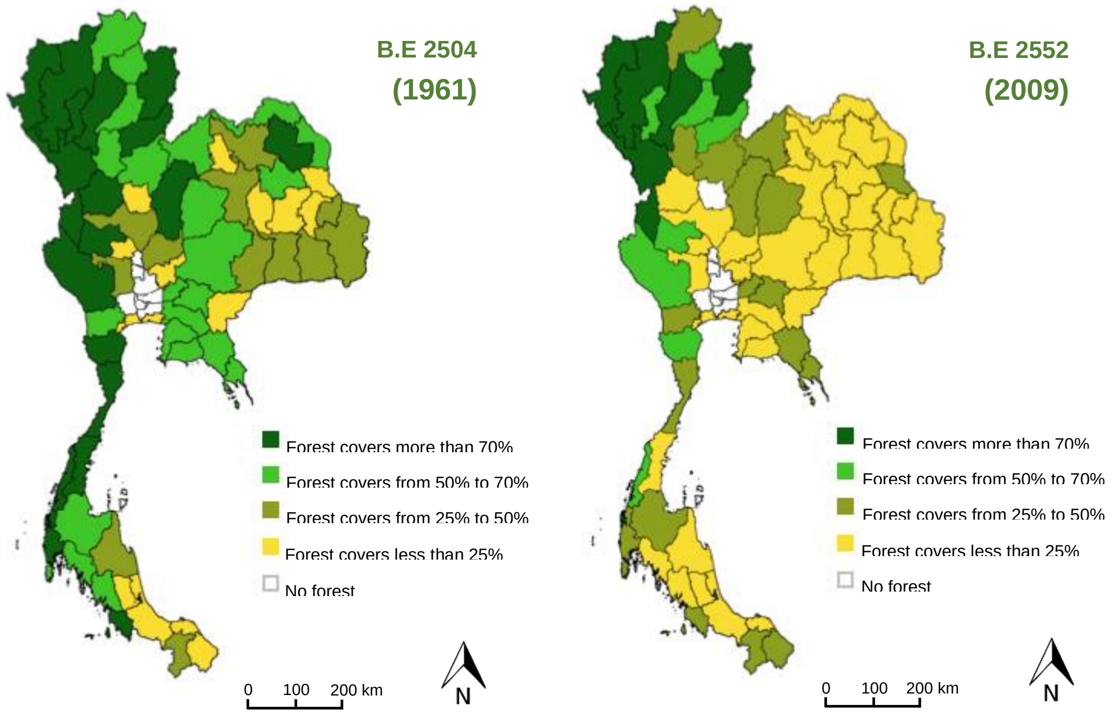


Figure 3.5 Comparison maps (loss of forest cover in Thailand) from 1961 and 2009

At the present, Thailand has forest covering 102,119,538 rai (1,633,913 hectare), approximately 31.57 percent (RFD, 2016) of the complete land.

The Thai Royal Forest Department (RFD, 2016 p.1) illustrated the major purpose of deforestation, the land encroachment. Those areas are used for residential development, agricultural expansion of farming land, growing business aspects (such as timber export) and the consumption of large areas for alternative energy crops, etc.

10 (Unit: 1 hectares = 6.25 Rai / 1 Rai = 1600 Sq.m)

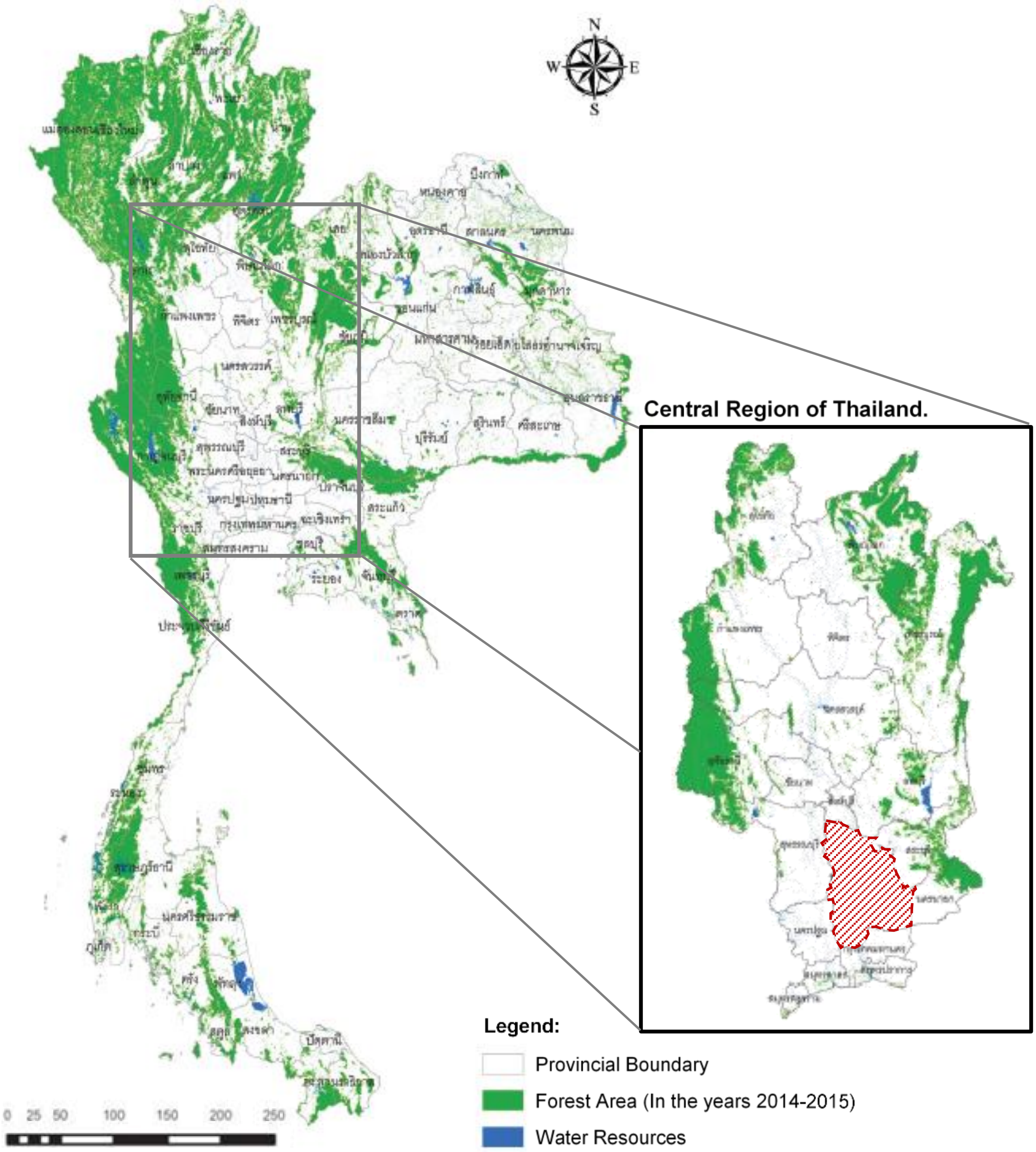


Figure 3.6 Thai forest areas in the years 2014-2015 (RFD, 2016)

This data, the measurements were retrieved from Satellite Remote Sensing methods (LANDSAT 8) with Image Interpretation of forest areas.

Table 3.1 Change in forest coverage from 1973, 1998 and 2013 in all regions of Thailand (RFD, 2016)

Year	North		North-East		East		Central		South		Whole Kingdom	
	Rai	%	Rai	%	Rai	%	Rai	%	Rai	%	Rai	%
1973	70,996,875	66.96	31,669,375	30.01	9,397,500	41.19	14,981,250	35.56	11,521,875	26.07	138,566,875	43.21
1998	45,660,625	43.06	13,115,000	12.43	4,691,875	20.57	10,030,625	23.81	7,578,125	17.15	81,076,250	25.28
2013	56,283,600	52.36	15,813,931	15.09	5,139,025	22.45	13,832,638	32.79	11,050,350	23.95	102,119,539	31.57
Total	**107,488,013**		**104,823,163**		**22,888,119**		**42,186,063**		**46,133,506**		**323,518,863**	

Surprisingly four provinces in the central area – Nonthaburi, Pathomthani, Ayutthaya and Angthong province – have no forests at all (red striped area) (Ibid).

Because of those reasons, Thailand has reduced forest in many regions in the last decade. The impacts extend to the environment and the degeneration of natural resources. More importantly, those situations led to more frequent flood disasters which happen in more severe events (ibid).

For instance, in the upstream area of the river, heavy rainfalls mostly trigger dangerous flash floods due to less forests, while the downstream area is facing with the lack of mangrove forest for coastal flood defense.

Human activities certainly led to a decrease of the Thai forest area, whereas the false interpretation of forest data which occurred because of errors in the used techniques made the forests area calculation not accurate and unprecise.

In the past, the limited resolution and availability of aerial photos for performing the calculation of the forest area led to false interpretations. Nowadays, the technology is more advanced (Landsat 8 Satellite) which makes the calculation of the Thai forest area more precise and accurate. Fortunately, it seems, that these errors provided calculations with less forest area than there really was.

Interviewee: Mr. Vissanu DOMRONGSUTSIRI
Director of remote sensing surveying and forest resources analysis
Royal Forest Department Thailand
Project for providing data forest land in year 2014-2015
(2016 November 17th)

However, current events of deforestations are still the main factor that causes flooding in Thailand and the need for support of the policy of re-plantation has never been higher. It seems deforestation issues have to be given priority over a careful reforestation in the future.

From my point of view, the plantation is one solution that has the positive benefit of biodiversity and the soil & water conservation, which can reduce the rate of deforestation and restore terrestrial forest ecosystems. A support by the policy of long-term forest management plans for re-plantation and promoting economic forest in the central area of Thailand has to be considered to successfully implement flood prevention and adaptation on local scale.

3.3 Flood forecast and early warning systems

3.3.1 Weather forecast and flood evacuation

The problem of the weather forecast is relevant with water management and flood evacuation. Uncertain weather has an immediate effect on the quality of forecasts, early warning systems and the communicating risk for flood warnings.

In the flood from 2011 in Thailand, there are some experts who advocate that the flood events were largely inevitable due to technological difficulties in the prediction of seasonal precipitation (METI, 2012) and another group of researchers revealed that one reason that caused the flooding may involve the uncertainty of the weather forecast (Mahajchaiyawong, 2013). Those issues are concerning the preciseness and accuracy of weather forecasts and the reliability of information for making decisions on preparation and evacuation. Accuracy and preciseness effects of weather forecasts on water management

According to the academic seminar of Environment Research Institute at the Chulalongkorn University, Bangkok. Thailand (2013) some of the participants were discussing that the weather forecast announced a trend towards a drought in the year of the great flood in 2011. Other officer groups who are involved in the water drainage and dam management therefore planned to have the water storage areas almost filled to the highest level. In the following, the uncertain predictions proved wrong (Anonymous, 2013). It rained more than expected and the water in the dams threatened to overflow, so it was necessary to drain the water to the downstream area. Likewise, the water level at the dams was up to a hundred percent which was why partly the water was released into the river downstream leading to a double mean amount of water in the river due to the water from the rain and additionally the drainage water (ibid). This mass flow of an enormous volume of water flooded many areas of the country by overflowing the river.

The National Disaster Council mentioned by Mr. Smith Dharmasaroja (2012), he pointed out that the water management of Thailand had to expect high rainfall in the year of 2011 due to the La Niña weather phenomenon. The government however did not pay attention to the warnings from the experts, with severe consequences.

This research provides more information about the problems of weather forecasts and rain data collection.

Firstly, the instruments of weather forecasting are not up-to-date which makes the information not continuously sufficient with a lack of clarity and quality. Therefore, the data should be re-checked with other sources such as the data from Japan, the United Kingdom, the United State, etc. (Anonymous, 2013)

Secondly, urban expansion makes it more difficult to operate the data collection and the measurements on rain gauge stations which were in agricultural areas in the past. The stations which are collecting rainwater used to be in less dense population while today they are in the urban sprawl with a high density of buildings and plenty highlight buildings (Amatayakul, 2013).

People who live nearby or directly at those rain gauge stations are also not satisfied when officers have to come on their properties to evaluate the collected data. Those are obstacles which prevent the needed access to information. More available information could improve the accuracy while predicting actual events and precipitation more precisely (ibid).

Finally, the rain gauge stations itself were found to be inadequate all over the whole country, which caused the forecast of precipitation and heavy rainfalls to be imprecise (ibid).

Interviewee: Mr. Porrames AMATAYAKUL
Director of Agrometeorological Division
Meteorological Department Bureau. Thailand
(2013 November)

3.3.2 Communicating risk in early warning systems

Uncertain and not accurate forecasting, monitoring, evaluation of information and early warning systems led to the severe experience of the devastating tsunami that hit Thailand in 2004. Early warning systems became an important tool for Thai communities for the awareness of natural disasters. Especially after 2004, a lot of technical support has been done to early warning systems (Rhyner and Jokob, 2014).

The quality information gathered during the tsunami and flooding is relevant for the future evaluation of early warning data. Not only is the technical support responsible for the failures in forecasting, but the understanding of the information and the reflection of the actions of local communities is as well. Since the warning systems and the data have improved, the trust in the warning source has grown.

In particular, for people it was difficult to get information about flooding and other disastrous events from the government which led to “frustration and panic” (Roachanakanan, 2014). The local authorities experienced inconveniences in announcing news to the public, which made it even harder to solve the flood problem for the decision makers.

Thus, providing forecasts and early flood warning systems should be an apparatus to combine meteorological forecasts, hydrologic data and other information. This information can be accurate, reliable and related in cooperation. Authorities of all levels should be involved in planning, supporting and improving the management, so that people in high-risk areas can prepare early enough for evacuation.

This warning system tools are important tools for saving lives. There are locations which are in such a high risk, that even early warning systems cannot warn the inhabitants rapid enough for evacuation. In this case, long term planning is important to avoid housings in those disastrous areas.

3.4 Private wall and public constructions for flood protection

3.4.1 Private flood wall

After the 2011 flood event, industrial estate groups are still located in flood risk areas, while future floods may still not be reliably predicted since the weather forecast is rarely certain. There is also no guarantee that there will be an effective process on flood management by the Thai government administration. Hence, the private flood barriers in the industrial areas are being constructed by the estate groups on their own in order to protect their territories independently. These structures obviously will have impacts on drainage patterns and lead to changes in discharges on the floodplain. It remains unclear how to cope with the next massive flood and whether the costly flood protection projects can decrease the problem physically.

From Survey: 21st October 2015

Figure 3.7 Private flood wall protection in Industrial Park, Ayutthaya province, Thailand (Author)

His point of view on development: "The dam wall protection which is located in industrial estate parks (for example, the Rojana Industrial Factory) represents one of the very good projects to protect against the flood".

After the national governmental group (the prime minister) visited the site to check the progress of the construction (31st August 2012) on the area where the flood occurred, the project was expected to receive more funds. In the future, some way of compensation measurement can be provided to the estates in order to support the construction of more dams to prevent flooding damages. These supports will furthermore support the local economy by giving the confidence to foreign investors to invest in Thailand.

Newspaper: Local Economic News
Mr. Tingthong Prayoon
The chief of Ayutthaya's Industrial Office
(2012 August)

During the survey carried out by the Department of Public Works and Town & Country Planning from 2012 to 2013, the surveyors conducted a field work in order to prepare and produce flood maps, covering the north of Bangkok capital area. The survey team reported that in this area it is not only the industrial estates who construct the private flood barriers, but also the local residents develop flood wall protection on their own. An interesting fact is, that the survey found those flood walls and other different structures have a variety of heights from 2.50 to 6.02 meters above the local ground level.

3.4.2 Public flood wall

Furthermore, Department of Public Works and Town & Country Planning has operated on a dyke construction along the Chao Phraya River as well. The project aims to protect the residential area from the flood. Nevertheless, there are positive and negative aspects.

Figure 3.8 The public flood wall protection in Singburi province (Author)

Positive:

- Mainly the flood wall protection aims to assist communities not to face with flood. Besides, the wall can separate human activities from interfering the nature and the ecological system, because it is not as easy to access the river as with the traditional flood defense (no wall). Thus, the fish and other aquatic organism can lay their eggs while being less interfered from fishermen.

Negative:

- In terms of huge floods from the up-stream, the river seems to be narrow and shallow because of more sediments and plants growing along the flood wall line. This way, the flood protection creates an additional blockage for the flood water.
- Loss of flood retention volume
- The flood wall protection can make the river narrower and generate a higher flood peak in a downstream area.

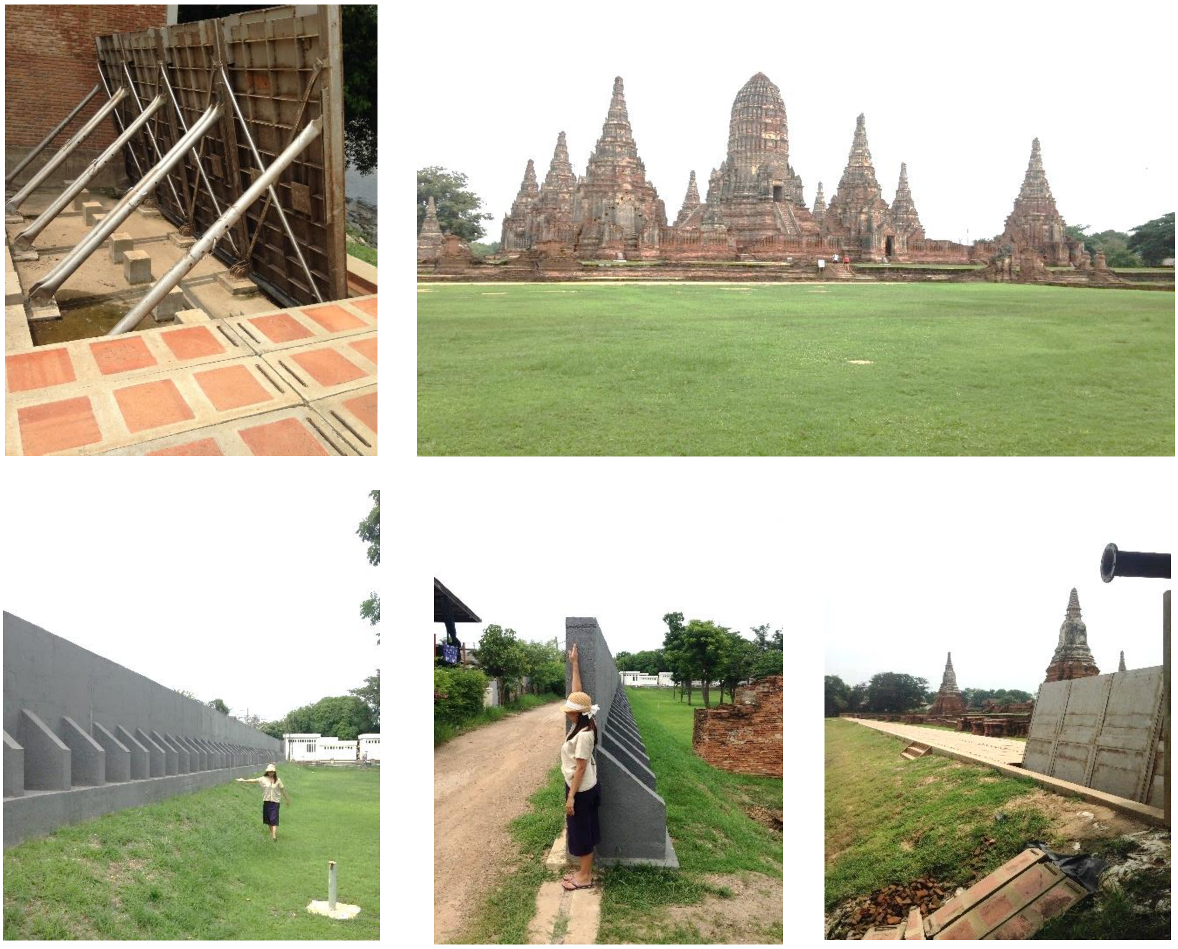


Figure 3.9 The public flood wall protection in Ayutthaya province[11] (Author)

From my point of view, currently there is no clear safety standard of construction and regulation. There is still no explicit report by the Environment Impact Assessment (EIA) on what could happen in the future when a mega-flood comes and whether the wall will be stable enough to protect or whether it might cause more damage and represent a bigger flood risk. This means that the human made high concrete flood protection is rather unreliable, because it changes the water drainage pattern and can have a negative impact on both, the environment and the flood constructions from the local communities.

3.5 Insufficient long-term flood and water management

"We keep too much water in the dam early in the rainy season, now at the end of the season we have to release a large amount of water at the same time, which causes floods".

Mr. Smith DHARMASAROJA, Head of National Disaster Warning Foundation

Newspaper Bangkok Post (2011 October 6th)

[11] A surveying flood area at Wat Chaiwatthanaram, Ayutthaya Historical Park, a UNESCO World Heritage Site

Another reason for the many severe floods in 2011 in Thailand is the insufficient water management of reservoirs and dams of the country.

According to the Electricity Generating Authority of Thailand (EGAT, 2015), the water management department of the government kept massive amounts of water in the dams since they were afraid of high water consumption during the dry season.

Several years in the past, Thailand had to face severe droughts, caused by unusual lack of precipitation and not enough seasonal raining (although seasonal raining was expected at that time, assuming the La Niño effect). The trend was showing serious problems for the future, like scarceness of the consumption of water. Unfortunately, there were many monsoons with heavy rainfalls in the northern part of Thailand, because the rain season came earlier than expected.

In this case, the water reservoirs were full already due to the expected drought, which forced the huge amount of water to flow down to the central plain area. These downstream areas – especially the areas right next to the dam – were severely affected. The discharging of the dam together with the catastrophic monsoon and heavy rain during that season simultaneously caused massive flooding and devastation in many areas lying below the dam. This flooding event was mainly caused by the failure of constructional systems and could have been prevented by better water management.

Committees of monitoring and analysis of the 2011 flood season in Thailand (EGAT, 2015) reported that their groups which were responsible for the management of water (concerning the monitoring and analysis during the flood seasons) made the decision to drain the water from both dams – the Bhumibol and the Sirikit – for reasons of agriculture, water consumption and requirement of electricity for industrial estate in cities.

According to the Strategic Research Water Management (DWR, 2015), the national project is still unable to tackle flooding progress, because of lack of policy coordination and no continuous implementation. After the great flood in 2011, the government spent a huge budget on compensating the impacts and did not focus on serious ways of solving the problem in the longer term. That is why other water crises are still not resolved.

In term of water crisis prevention, *“Thailand still has problems with floods, droughts and water pollution and these problems are recurring from time to time”*.

Interviewee: Mr. Pipat RANGNGAM
Director of Water Crisis Prevention
Water resource Department, Thailand.
(2015, September 7th)

There are some more reasons why the current flood protection and adaptation situation in Thailand has not been optimized by now. The main reasons are listed in the following:

- A lack of collaboration and clear formulation of the water management and the planning policy to finally implement the coordinated work into project reality.
- A lack of social interaction and participation concerning the water management.
- Many departments and local authorities are working on their own way of water management. That's the reason why there are independent works on the same problem without cooperating with each other. It can suggest on "single command center".
- The Government focus on solving the problem with structural measurements and many short-term solutions which have been not highly developed by considering sustainable long term projects on water management.
- Less powerful law enforcement concerning the water management

Presently, there is still no new flood management long-term plan (Roachanakanan, 2014).

The fact that the flooding occurred at an unexpected time meant that there was only enough time to prepare an emergency plan, designed especially for this short term. Mostly, local authorities are solving flood problems on their own. However, in high residential areas they need some urgent assist from social volunteers, public service and military, which has to support the mitigation of floods.

This is caused primarily by a lack of effective management of water resources and ineffective means of water usage, without considering the conservation. Flood is still a big problem to deal with. From my point of view the basic step of solving these problems is to improve and re-organize the overall management of risk and vulnerability on water management. To cultivate national consciousness of the responsibility for the next generations is reflected in sustainable water management.

3.6 Ineffectiveness of land management in practice

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) indicated that the land management is a key instrument for achieving several objectives (GIZ, 2011). Land use planning is one of the tools of land management which can contribute to the reduction of disaster risks, such as flooding and landslides (ibid). The frequent devastating flood events in Thailand are one of the major concerns caused by inappropriate land-use practice and loss of forest cover (LDD, 2015). Likewise, urban planning, land management and the water drainage seem not well-organized and in some risk flood-prone areas have never been preceded in design and plan.

Anthropogenic activity has detrimentally affected the hydrology of river basins because of ineffective land allocation.

According to Puchaneyapongsakorn and Khongouan (2011), who studied the land regulation which is also not strictly applied, the law's controlling power is insufficient when it comes to the local communities, because the legal punishment is not strong enough and the fine is as well relatively low (increasing enforcement and imposing strict penalties) In some parts of the law and regulation enforcement, it seems to be a great deal to adapt the legal challenges for every land law and zone separately.

Moreover, the UNISDR (2013) reported that the flooding in 2011 highlighted the ineffectiveness of land use regulation enforcement and the cost of improper or inconsistent land use development. The insufficient fragment control of urban & rural planning and the lack of land management could be an obstruction to natural flood drainage systems. For example, private constructions from real estates located in flood plain areas – such as the ones described earlier – have only been concerned for short term economic gain, regardless of the sustainable use of the land and the long-term planning of flood impacts.

The Department of Public Works and Town & Country Planning (DPT, 2013) in Thailand is one of the authorities which is responsible for land use zoning regulation enacting by the Town and City Planning Act of 1975 and 1979. Land use zoning divides any parcel of land into various zones, each of which has an exclusive venue for a particular scope of activity. This zoning ordinance could be profitable and more effective when it comes to the implementation of limiting and controlling the urban development (Dennis & Ramm, 2015). Similarly, the implementation of strongly prohibiting encroachments in flood plain and other flood-prone areas in Thailand could be a real benefit in the long term.

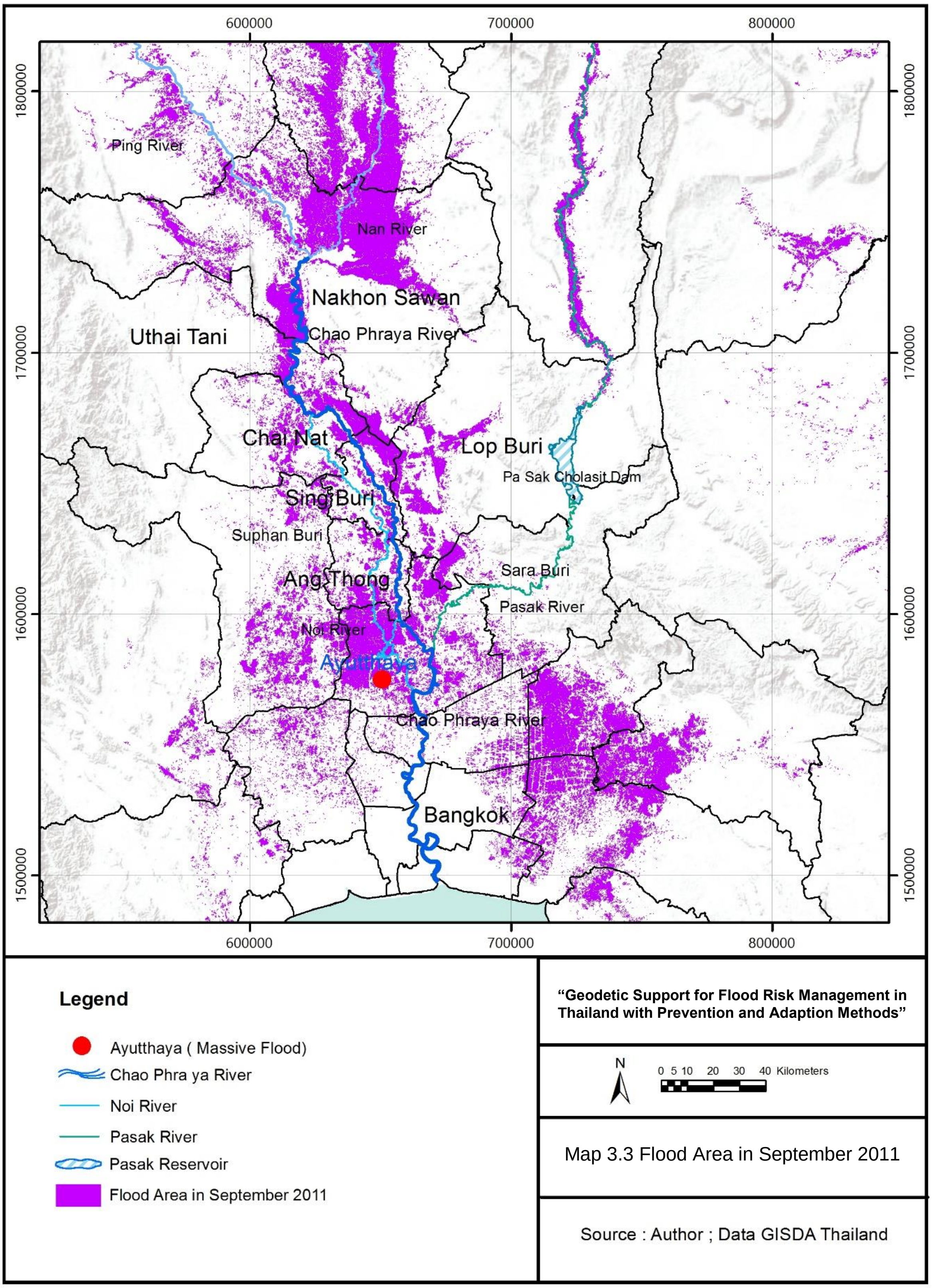
Meanwhile, when considering land use zoning it is noticeable that there is still an *inadequacy of green areas* in cities, not only in Thailand but worldwide. The green area ratio is an essential environmental sustainable zoning regulation that sets standards for the landscape and the site design to help reduce storm water runoff, improve air quality, and to reduce high temperatures in the city (DDOE, 2015).

Proper water retention is another potential purpose of the conventions on the topic of flood events. Therefore, land use planning and zoning by providing open space for water preservation contributes to the mitigation of severe floods by identifying areas for forest protection or afforestation (GIZ, 2011).

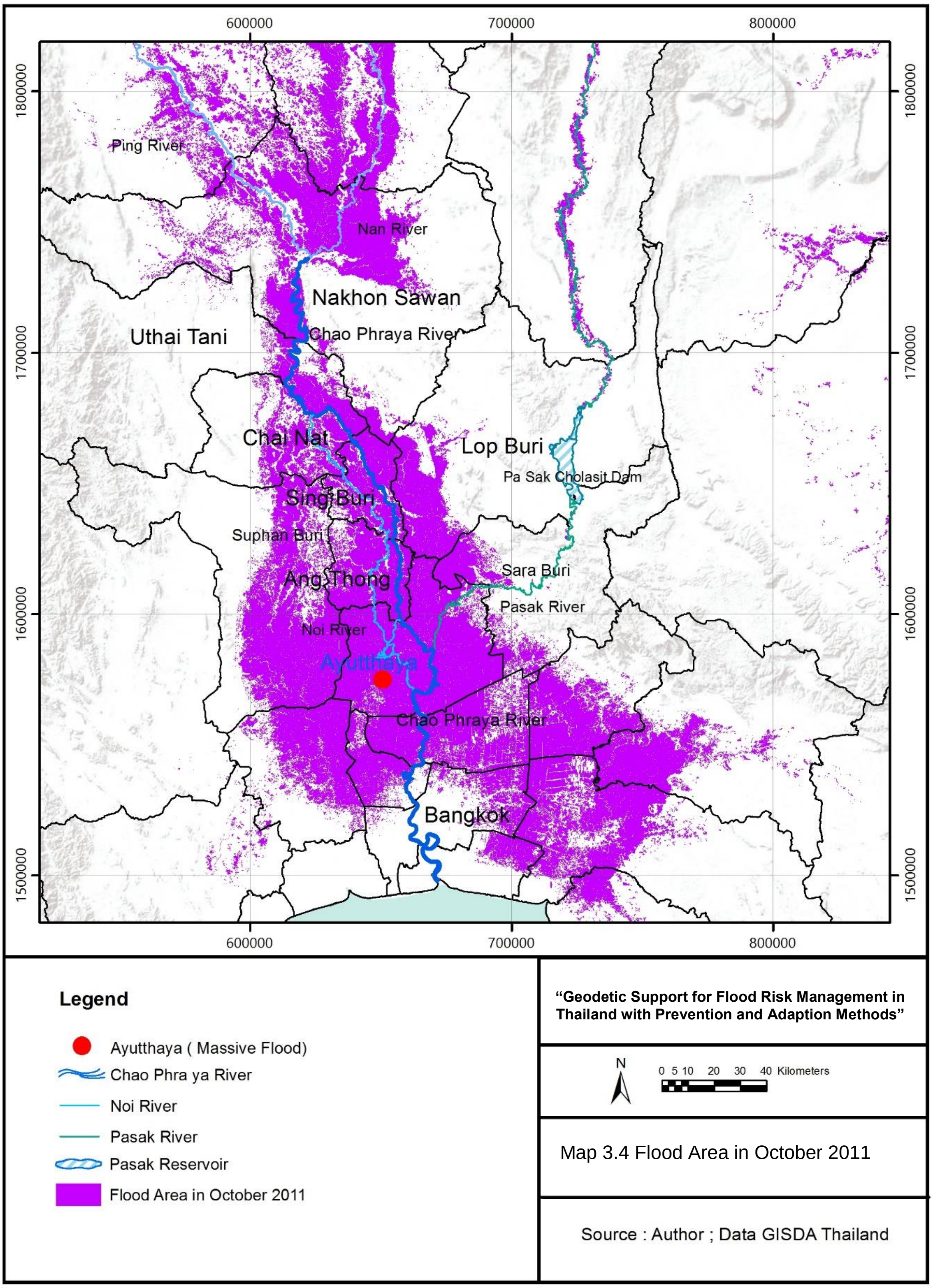
The World Meteorological Organization (WMO, 2007) also suggested that the flood protection should be synchronized with the land development by making flood risk management an essential part of land use planning. This is extremely important in order to reduce the risks involved in today´s rapidly ramifying of urban areas upon flood plain zones. According to the Associated Program on Flood Management (APFM, 2008) there should be a better coordination between land use plans and water management. The regulation should be devoted to the sustainable land use planning, which would significantly lower the flood risks in the area. Furthermore, the local disaster management authorities should be the one to ensure that the regulations are properly set into practice.

The following figures show the flooded areas of central Thailand from September to December 2011.These provinces are highly populated and had no efficient in land management which lead to the inundated flood lasting for many months.

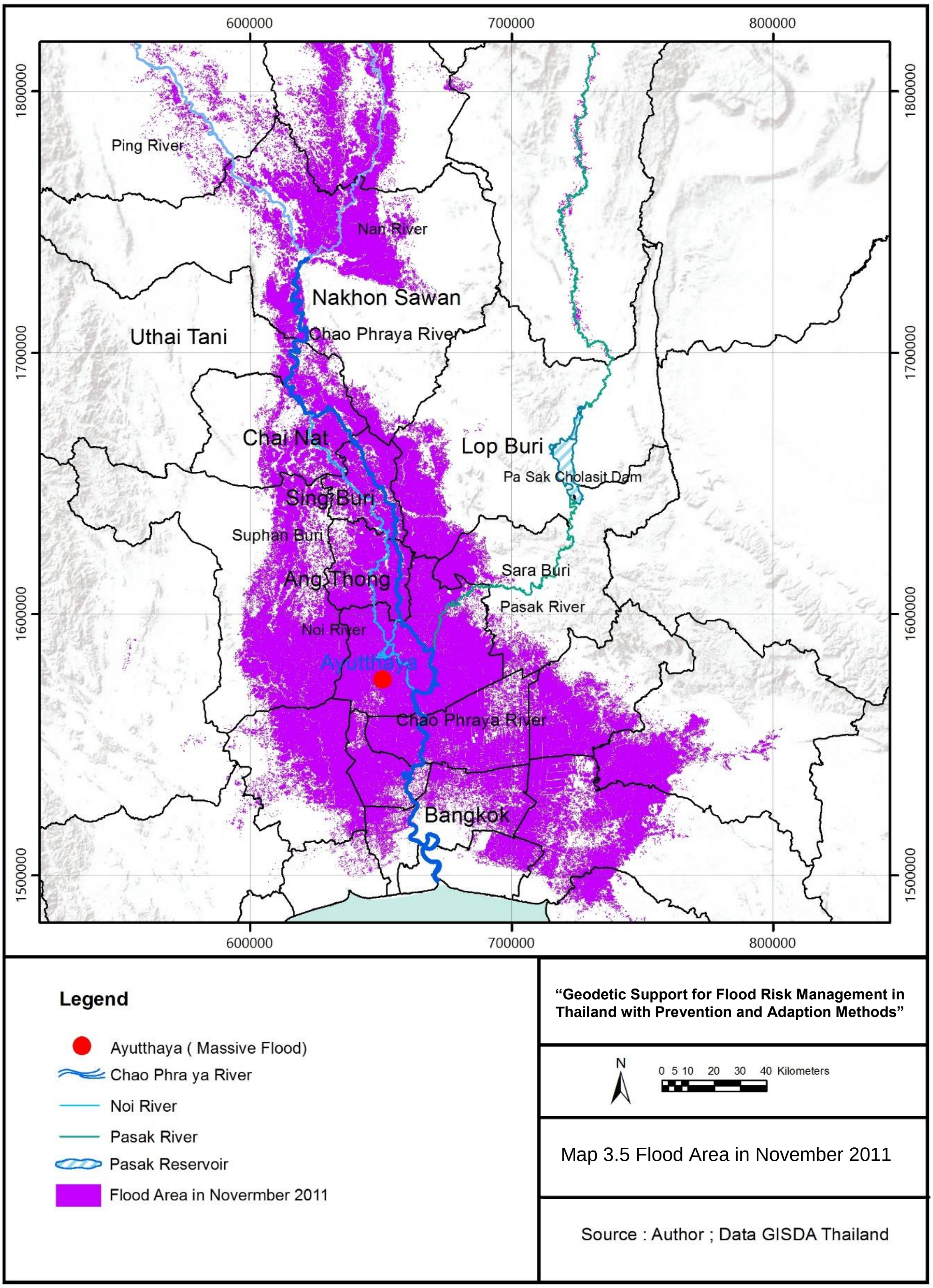
Overview of Chao Phraya River Flooding from September-December 2011



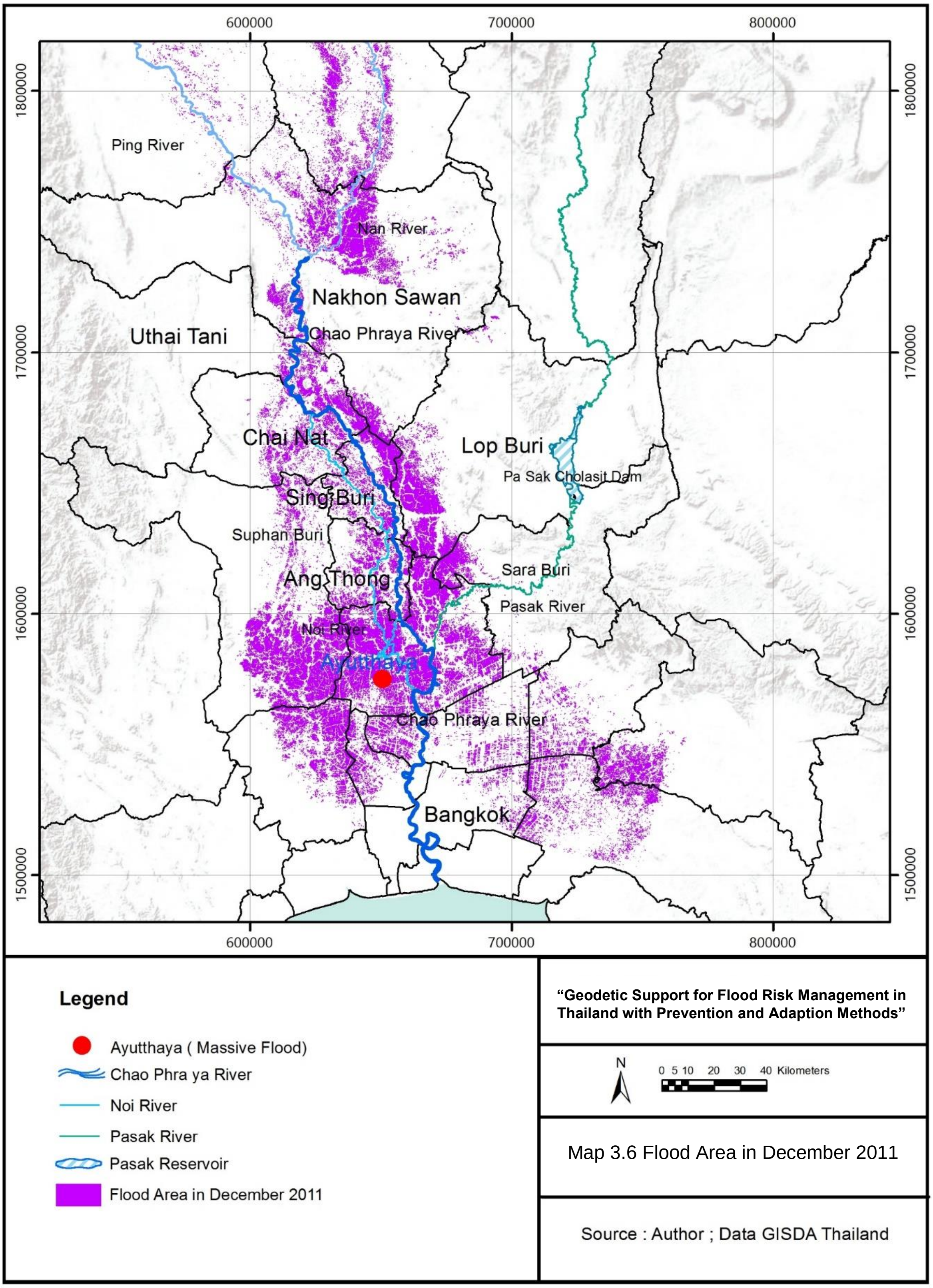
Map 3.3 Flood Area in September 2011



Map 3.4 Flood Area in October 2011



Map 3.5 Flood Area in November 2011



Map 3.6 Flood Area in December 2011

The land development and constructions in Thailand are mainly regulated by two laws. The Building Control Act and the Town and City Planning Act, both of which have been continuously revised and changed starting in 1992. Those two acts are the ones that could be able to support the land planning by reducing the risks for people and infrastructures.

Living in flood risk areas is possible as long as there is an adaptation of the constructions following the building code (DPT, 2013). According to DPT, “the Building Control Act deals with the rules and regulations issued by the Thai government for the appropriate procedure in the construction of the property. Particularly, it enumerates the various applications needed for constructions, buildings and restriction requirements and the corresponding penalties for failure to comply with such measures.” The building code is also concerned with the flood management by building infrastructures to protect communities against excessive flooding, relocating buildings to areas that are in a higher altitude and therefore not in the area of the flood plain as mentioned above (topic 3.1.2 urban expansion and the suggestion of the Thai traditional housing style).

The construction of flood defenses, especially levees, storage reservoirs, floodwalls, and water diversions by local people has led to a hazard of severe flooding because of misidentified and mistaken solutions to the water management problems. Contrary, the land use planning should use methods and development decisions based on the expected future risks in order to make a sustainable flood mitigation and adaptation plan for the area, which could also make people´s life with the nearby water possible (Knieling, 2012).

In my opinion, the land management teams should always involve the consequences of flooding in their plans. This is crucial when it comes to developing a proper strategy concerning the possible risks and ensuring approval from the society. The suggestion could be that along the river only temporary buildings and outdoor activities should be allowed. Thus, making a proper land zoning and introducing a strict building restriction is essential.

This is possible by identifying safe locations in the flood plain areas and constructing settlements which are properly adjusted for flood adaptation (IPP, 2011). A suitable organization of the land by applying adequate building standards could be one of the greatest measures to prevent and to adapt flood risks in the future.

3.7 Lack of sustainable participation and collaboration by the administrative authorities in flood mitigation and adaptation

Apart from the land management (as mentioned in topic 3.6), sufficient long-term flood and water management were not able to take place when the policy could not be put into practice. Hence, coordination and cooperation between organizations are necessary and they play a crucial role in the effective and successful water management.

Thailand after the flood in 2011 still has no clear position on water management and on the entire perspectives of the main policy (Tingsanchali, 2012). Many organizations have not been able to use the authority to manage the water resources in a comprehensive program or even take part in combining the flood mitigation and the adaptation plan. The problem of the unclear participation and long-term sustainable flood management projects is that the government agencies mostly only take responsibility for emergency cases (ibid). More effective plan should be a solution for the flood issues that takes not only short-term but also long-term planning into account.

The working tasks of responsible agencies are often overlapping, which causes problems from time to time (Marks, 2011). Moreover, the government agencies accuse each other for the issues of plentiful structural methods on flood prevention without participation. This also leads to the failure of the associations to continue their flood management cooperation (Roachanakanan, 2014).

3.7.1 Strategic Committee for Water Resource Management (SCWRM)

The U.S. Agency for International Development[12] (USAID, 2011) reported that Thailand has never been enacting on a law of managing water resources. The administration of water resource, managed by a department of the Thai's government is involved in 30 state organizations in more than 7 different ministries and integrated in over 50 laws (ibid).

As a result, there are overlapping working tasks. For instance, the Department of Irrigation, the Department of Marine and the local administrative organizations (LAOs) are three administrations which are authorized equally to work on similar duties such as irrigation, re-canalization, flood prevention and water transportation on their own method (Agenda 21 Thailand, 2011). Reducing an overlap in working tasks may be useful for an efficient cooperation. This will maintain the relationship between governments to establishing flood disaster management policies.

Thailand has started cooperation by setting up the so called Strategic Committee for Water Resource Management teams since 1989 (SCWRM). These teams, headed by the Prime Minister, were ordered to draft a water and flood management (Nikomborirak & Ruenthip, 2011).

The SCWRM developed a master plan, recommending the establishment of three organizations (Ibid). These are listed in the following:

(1) The National Water Resources and Flood Policy Committee (NWRFPC) responsible for the formulation of the flood management policy and the proposing of the budget allocation for the cause.
(2) The Committee for Water Resources and Flood Management responsible for executing the adopted policies and measures.
(3) The Office of National Water Resources and Flood Committee, which is the secretariat body.

The committee – persisting of three sectors – has played a major role in flood management even though it is not getting any support by legal authorities. The committee is allocating the budget to invest it on large-scale infrastructure projects to prevent flooding, for example by

[12] U.S. Agency for International Development. USAID's Regional Development Mission for Asia (RDMA) related to trade and natural resources management

constructing special flood ways and water reservoirs (Conben, 2012). Nevertheless, local communities are still suspicious about the transparency of the project and doubt that the cost effectiveness of the construction will be adequate and appropriate for mitigating potential risks.

3.7.2 Participation and effectiveness for water governance

The International Union for Conservation of Nature (IUCN) stated that a top-down approach on the cooperation and participation for the water management takes influences on the process of decision making of municipality authorities. The local residents are not able to express their genuine ideas because they have insufficient participation and this affects the local communities heavily. Their decisions are sometimes entirely made at high level and often result in local conflicts, reduction of natural resources and negative impacts on local communities and their livelihoods.

Hence, the government agencies, which were involved in flood events management, still have the challenging task of collaborating the bottom-up and the top-down policy. The cooperation becomes even harder to achieve when the leader of the involved communities is from competing parties, which have various political ideas and different backgrounds (TRF, 2013).

The government needs to listen to the communities in a more participatory approach and has to consider the different critical point of views of each stakeholder-driven water governance and river basin management. The municipalities should work as centralized authorities which bring all the ideas together and attempt to solve the flood problem by brainstorming and public hearing (Neef, 2008).

This re-organization will bring a better result in flood managing. With those agreements, the majority group will be satisfied. However, improvements have to be done in participation and cooperation among government agencies themselves and between the national government and local authorities. In addition, to achieve a higher effectiveness of flood management in Thailand (The Work Bank, 2012), these improvements should consist of actively sharing information, linking data, preparing flood disaster damage evaluation and developing capacity buildings for enhancing the training.

3.8 Chapter Summary

Certain anthropogenic inventions are obviously exacerbating the impacts of flooding. The seven major issues illustrate that flood disasters are not only caused from climate change (as described in Chapter 2) but also from the human supremacy. Human activities can have even more impacts in the future. The problematic issues of artificial actions can be grouped into tree main topics: the rapidly developing factors, the technical factors and the administrative factors as a consequence.

Firstly, the group of the *developing factors* is concerning the environmental effects of the dramatically increasing urban and rural development, including human settlements, urban expansion and deforestation. These developments are inadequate for the ecosystems along the river from the spring until the estuary. The issues concern the land, water and environment and have no benefits for the natural ecosystem and human-kind.

Thereby, this section provides the suggestion of the method of sustainable development. An urban development is expected to provide a green infrastructure[13] (Europa, 2016a) or blue – green concept, and extended cities or re-settlements should be located in safe spots in the flood prone area while having enough space for water retention, channel diversion, more canals and recreation areas. Furthermore, plantation at the riverside habitats have various valuable benefits, such as an increase in biodiversity, providing a buffer-zone from water and a reduction of air pollution, which is moreover reducing the acceleration of the climate change. Well-managed human activities, economics and social benefits let the future generations live in harmony with the environment in the new settlements.

Secondly, *technical factors* such as the uncertainty of flood forecasts and early warning systems and the private and public flood wall constructions may create foreseeable flood impacts. The emergency response to flood disasters are focused on short-term management, whereas for the preparation of certain areas for future flood impacts, a cost-beneficial solution for the capital investment on flood early warning systems and private and public constructions also needs to be created in a proper way and very closed cooperation between organizations.

Also, the maintenance of up-to date technical instruments for weather and flood forecast on national scale is an essential requirement. The maintenance of these instruments is a better solution than only taking action when the replacement of the flood prevention structures is absolutely needed. While the technical instruments are maintained, this opportunity can be used to consider non-structural measures in the process to further adapt the constructions for the flood protection.

Finally, more attention should also be given to *the administration factors* which involve insufficient long-term flood and water management, the ineffectiveness of land management in practice (In plan Implementation) and the lack of sustainable participation and collaboration by the administration authorities in flood mitigation and adaptation. The planning, design and management of flood preparedness is essential for communities to not solely be dependent on short-term plans in case of an emergency. More importantly, the short, medium and long-term plans[14] have to work together and jointly establish future tasks.

However, the long-term view is leading the present strategy and policy to a well-performing framework under the future climate scenarios. The implementation of the regulation on local scale is important while the cooperation among organizations and other stakeholders are necessary. Especially in flood alleviation, not only the plans have to be suitable and well-designed, but equally important is the consideration of the decision–makers and the financial supporters, because mostly with the support of these local authorities, the successful implementation of projects is guaranteed.

The next chapter focuses on the European experiences and how to minimize the risks of flooding, the successful key on flood management, guidelines and the present of the Thai flood management.

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[13] *Green infrastructure planning* is a successfully tested tool to provide environmental, economic and social benefits through natural solutions and help reduce dependence on 'grey' infrastructure that is often more expensive to build and maintain (Europa, 2016a).

[14] Thailand in the short-term (3 years), medium (5-10 years) and long-term (approximately 20 years) planning, in comparison to European countries (and UK) with respectively 25, 40 and 100 years.

4 Flood Management in European Environment

Flooding has continuously been an important topic for Europe. Since the nineteenth century, the European cooperation between countries trends to mainly support the planning of river basin scales, appropriate environment, sustainable assessments and an improved usage of a variety of techniques, which are available for flood risk management (McBain, 2012).

This chapter reviews the challenges of flood management the European countries have faced with many different experiences. The first section defines the EU policy; with the examples of a legal basis for transnational cooperation and the difference of flood protection and planning law among EU cooperation on Elbe river, the remarkable international cooperation of the Rhine river (room of the river concept); in practice on the case of water retention area nearby Cologne, the spatial planning of the Elbe river, the experience of the Simbach blockage which led to a flash flood, the future plan the Danube river line of the “flood protection action program 2020” of Bavaria. Finally, the most interesting practiced are highlighted in multi-development is in the new Danube “Entlastungsgerinne” in Vienna, Austria providing multi-benefit for flood management in mitigation and adaptation in nature.

4.1 European Flood policy (EU Flood policy)

4.1.1 The European Union flood protection and planning law

The European Union (EU) enacts the top policy for their member states. It creates the main aim action plans and programs for floods. Since 2004, the European commission (EC) aims to set up cooperation between the EU and their countries for flood prevention programs and uses those measures in order to reduce the flood damages (Europa, 2016b). Those measures are as follows:

- Improving coordination and co-operation by means of the development and the implementation of flood risk plans for all river basins and for coastal regions where human health, the environment or economic activities are threatened by flooding.
- Developing and implementing flood risk plans by means of planning and communication.
- Facilitation of the exchange of information and knowledge and sharing development experiences to promote the best practice.
- Development of closer links and co-operation between research institutions and public authorities in charge of water management and flood protection.
- Improved coordination between relevant EU policies.
- Promotion of a better awareness of flood risks by the inclusion of the public in discussion while improving the communication between the public and the authorities.

4.1.2 The legal basis for transnational cooperation

The legal basis for transnational cooperation consists of three general topics:

- International treaties
- EU community law
- Basis for transnational cooperation within the national law

The legal instrument plays an important role for grouping the territorial cooperation. This section of the chapter will provide an overview using the example of the Elbe River (ICPER, 2009).

Firstly, international treaties are, for example, treaties between Germany and the Czech Republic with other bilateral agreements such as the “Neighborhood Agreements”, “The Environmental Protection Agreement”, and “The Frontier Waters Agreement”. The agreements for the international commission for the protection of the Elbe (ICPER[15] – which tasks response to the main cooperation on the Elbe river project) and their present working groups have not constructed a law instrument for the commission, the action plans and the activities up to now. Their contract is established as a commitment on political level (ibid).

Secondly, the EU community law concerns spatial development, flood management and especially the Strategy Environmental Assessment (SEA) and environmental impacts (ibid).

Thirdly, the basis for transnational cooperation within the national law is especially concerned with Germany and the Czech Republic. Identifying differently flood law from country to country, the German federal focuses on their own national law of spatial planning, the Water Act etc., while a part of the Czech Republic is involved their flood prevention framework conditions, the Czech Water Act and the Czech Building Act (ibid).

From this point of view, administrative tasks have to be developed, if the international cooperation demands to be a robust team work cooperation. One more task that the cooperation is supposed to do in that region is to help combining the working groups with the local public level. Working closely with the communities (bottom-up) will result in good agreements from the local perspective and real working experiences. Hence, local co-operations will support the work of the international cooperation in that region. This local process will lead to a more effective work on border projects and other projects together in the future.

4.1.3 The difference of flood protection and planning law within EU cooperation

Each country of the European Union, especially the countries involved in the ELLA project, have been using the legal basis of five countries – Germany, Czech Republic, Austria, Poland

[15] IKSE (Internationale Kommission zum Schutz der Elbe); International Commission for the Protection of the Elbe River (ICPER, 2009)

and Hungary. They apply the flood protection and planning law on the spatial planning which is focusing on different acts. Several legislations are concerned such as the nature protection law, the soil protection law, and the legislation on agricultural land use, forest, building law and water acts. These instances can be summarized in the following:

Germany, has laws to improve the Preventive Flood Control, which involve several acts such as the Water Act (WHG), the Building Code (BauGB), the federal Spatial Planning Act (ROG), the federal Act on Waterways (WaStrG) and the Weather Service Act (DWDG). The Federal Water Act and the State Water Act, mainly focus on laws for water quality than on laws for flood protection measures. Legal structures integrate flood protection and spatial planning. Specific areas on flood plain areas are based on flood levels of a 100-Year-Flood (HQ 100). When the flood level is higher than a 100-Year-Flood (> HQ100), those areas are additionally included in the risk zone area.

The actual action plan was approved for flood protection by the International Commission for the Protection of the Elbe River (ICPER). The action plan has been the cornerstone for the Czech-German cooperation during the implementation of the flood risk management plan and the flood prevention measures within the Elbe River basin.

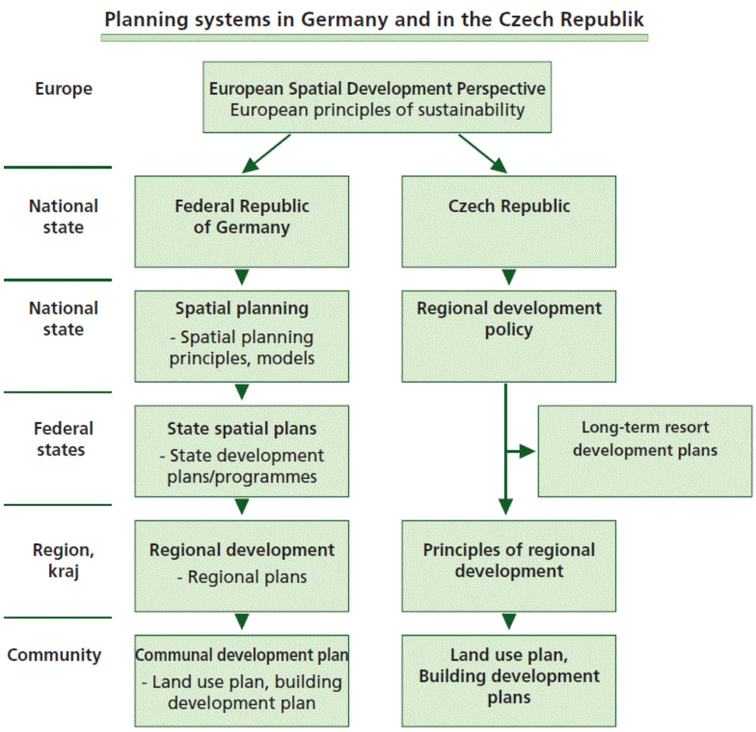


Figure 4.1 Planning systems in Germany and the Czech Republic (ELLA, 2006 p.8)

The water planning in the ***Czech Republic*** *is* relevant for sectoral planning instruments such as the Water Act. Specific planning is used for river basin and sub-river basin plans. These plans refer to the flood protection and the water quality issues. The Building Act is involved in the spatial planning and is applied on district level. In practice, the flood protection areas are included in the land use plan, which also have restricted control of the land use activities.

The law allows settlement for specific purposes in some areas of the flood plain basin, called “Active Zones” (ELLA, 2006). Those settlements are suggested for these zones to utilize the land as recreational facilities, camping sites, etc. However, the river authority of the Czech Republic is responsible for the active zones under the basis proposal (ibid).

The Czech Republic also has strategies and programs which have been adopted for the spatial development policy and the flood protection strategy. The Ministry of Agriculture is not the only section implementing programs for preventive flood protection and erosion control of agriculture soils. Besides that, the Ministry of Regional Development[16] is having guidelines for the integration of flood protection, concerning the zoning plans for communities (Land use planning) (ibid).

The flood protection of ***Austria*** focuses on the “Forestry Act” of the federal level. The flood planning measures and the management of forests will support preventive flood protection, which is concerning the hazard zone plan. The hazard zone is likely affected by events such as erosion from mountain streams, avalanches and other natural hazards. The plan is based on the water level of a 150-Year-Flood (HQ150) (ibid).

On the level of regional planning, the spatial planning focuses on the protection of settlement areas, main roads, rail connections and other valuable areas from damages caused by disasters. For the spatial planning, the local plan is implemented in detail. The creation of hazard plans for restrictive areas on the local level is an application of the Austria Water Right Act (which is identified by a flood plan based on a 30-Year-Flood (HQ30)). For example, when the retention area is dangerous for living, then the local plan will not suggest developing activities in that risk location (ibid).

The water planning issues of ***Poland*** are regulated in the Water Act (WG), in which the flood and the drought protection plans are included. The Planning and Land Use Act is involved in three levels of the land use policy: the national, the regional and the community level. For flood protection areas, the Polish law has different laws for rapid (imminent) risk of flooding and potential risk of flooding. Thus, the flood plan will be firstly designed to solve the flood problem of a high-risk area with river banks and dykes. Later, the potential flood area around the high-risk area (outside the dyke) will be designed for the case of a dyke break (ibid).

The water management of ***Hungary*** is regulated in act no. LVII from 1995, which aims on water management, water ways and lakes. Afterwards, the act from1995 was improved in 2004 to have flood protection areas and landscape developments. In the 19th century the Vásárhelyi-Plan, improved the discharge of flood water and increased the water retention capacity of the large-scale flood polders. In addition, the better water use and management led to more sustainable land use. After that, the Act no. XXI from 1996 added the land use plans for the national territory, the regional boundaries and other special districts. The Hungarian water management has been developed from the year 1997 until late in 2006.

[16] The situation of water planning in the Czech Republic is the same as in Thailand. The difference is, that Thailand still does not have a zoning for flood areas in the obvious view of regulations and district laws.

The purpose of the update mainly focused on the use and development of river banks, flood plain areas, and most importantly, the value of restricted risk zone areas (ibid).

It is remarkable that the five countries have a different focus on the manifold Acts, but still have joint activities and shared responsibilities for the flood protection projects. In comparison, the flood protection of Germany, Austria, Poland and the Czech Republic (which is mainly based on Acts) focuses to integrate river systems and river management. Austria lays emphasis on the Water Right Act and is combining it with the Forestry Act to deal with the flood management. Hungary is not only using flood prevention plans, but also trying to earn some more benefits by optimizing the usage of the river basin areas (ibid).

"The implementation is therefore calling on all such parties and authorities to join the transnational network of communication and cooperation, or to become a member of the transnational partnership.

The result of the ELLA project as presented here has been coordinated with the project partners at the various national and regional levels, as well as with the Elbe Flood Action Plan of the International Commission for the Protection of the Elbe (ICPE) and its implementation. Building on the cooperation with the ICPE, this publication can be considered an addendum to the above flood action plan. While the ICPE is primarily concerned with issues that are the responsibility of the national and state environment protection authorities, the results of ELLA focus on activities of the bodies in charge of spatial planning matters." (ELLA, 2006 p.5)

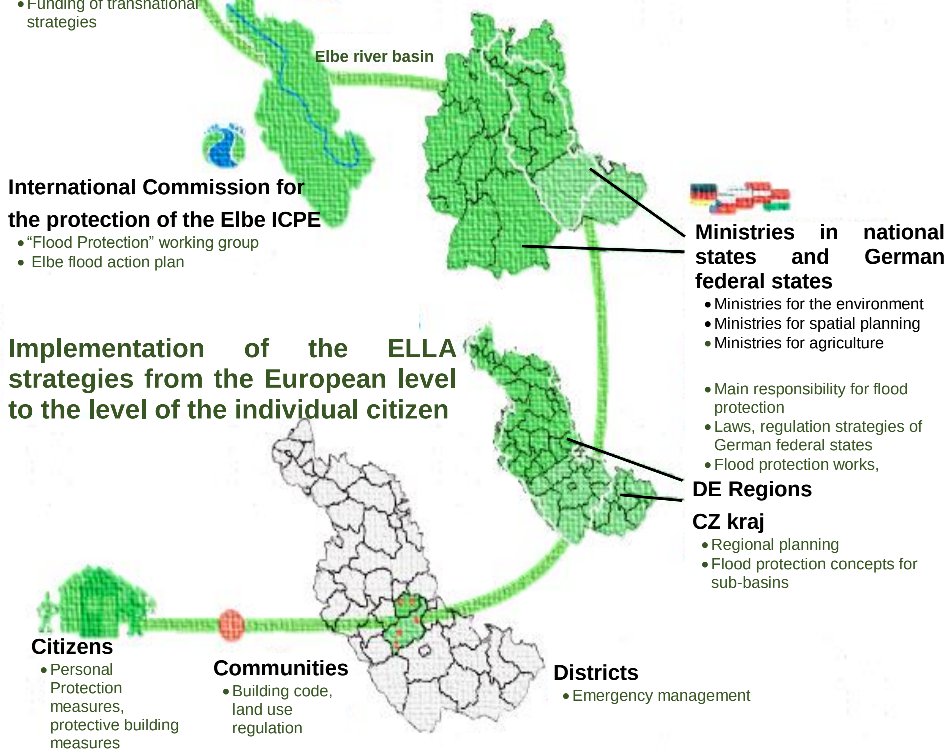


Figure 4.2 ICPE and ELLA Strategies (Top-down policy) (ELLA, 2006 p.5)

In conclusion, the water Act is one main legislation, while each country needs to have its own order to deal with flood risk situations. Other Acts such as the Building Code or the Forestry Acts are contained information completely with the legislation and the support of the whole river basin stream. In the same time, the interaction between the laws from the national, regional and local levels are relevant for the flood management. Together with the spatial planning it will result in more efficient coordination and cooperation across transnational river boundaries.

4.2 International Cooperation on the Rhine River

The European commission provides several measures aiming to reduce the severity and damage caused by massive flooding. However, many different measures still must be implemented such as: spatial planning, insurances, increasing awareness, flood forecasting and warning systems, civil contingency planning and the establishment of community flood plans and the implementation of physical interventions.

The cooperation of the Rhine basin consists of five countries - Switzerland, Germany, France, Luxembourg and the Netherlands, where the mouth of the Rhine is located, as the Rhine flows into the North Sea.

Germany and the Netherlands are part of the Rhine basin where mostly a population with a high density and intensive community activities is located. The land use along the Rhine basin has changed to be beneficial for agriculture while also providing advantages for the industrialization and urbanization (Duel et al., 2001)

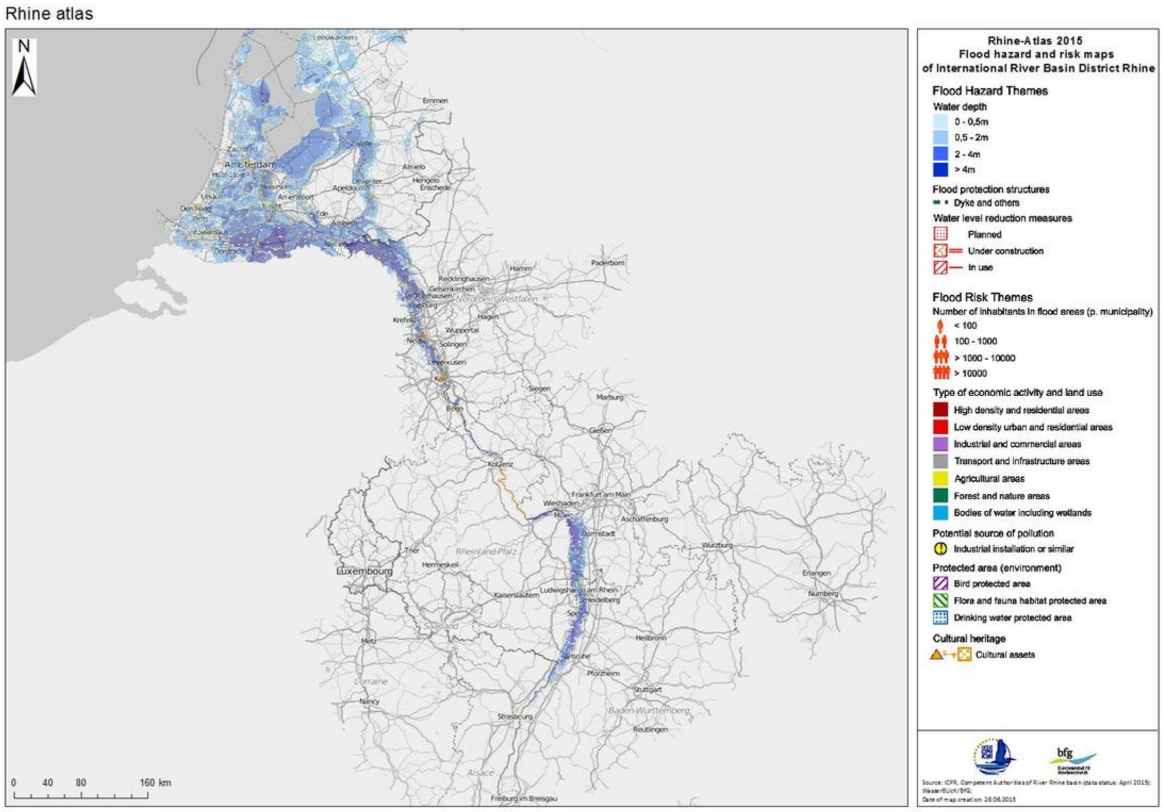


Figure 4.3 The Rhine Atlas 2015 (ICPR, 2015a)

4.2.1 Topographic and hydrological character of the Rhine River

The Rhine River is the largest river system in Western Europe and the third biggest river in Europe. The total length of the river is 1,320 km and the river catchment area comprises around 200,000 km^2. There are approximately 58 Mio inhabitants located along the 1,233 km main stream. Flood events occurred in the years of 1926, 1993, 1995 and the latest in 2015 which were caused by an extremely high water level.

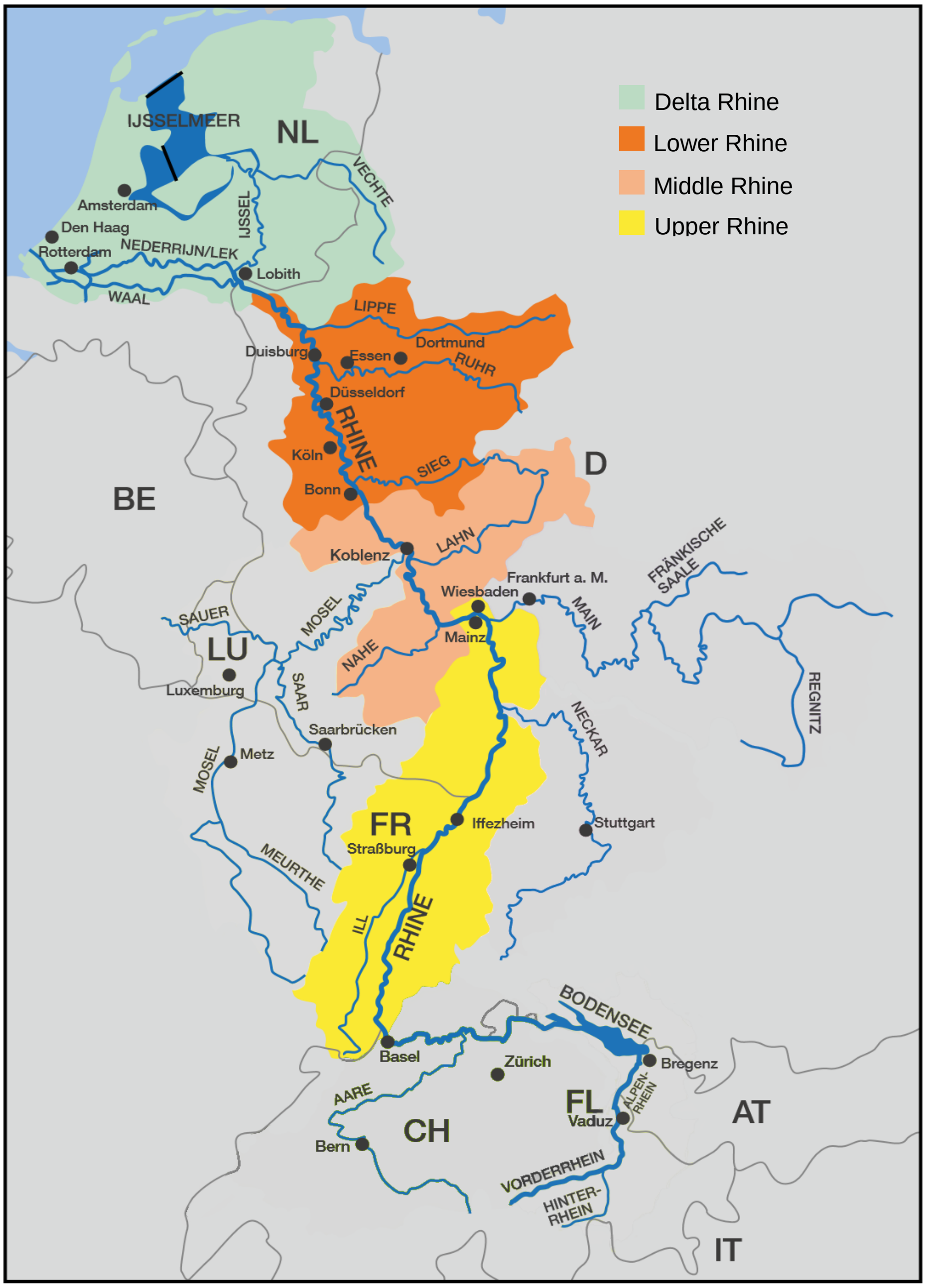


Figure 4.4 The Rhine River (ICPR, 2013 p.30)

The following pictures demonstrate the flow of the Rhine and the changes of the landscape along the river within the past 200 years.

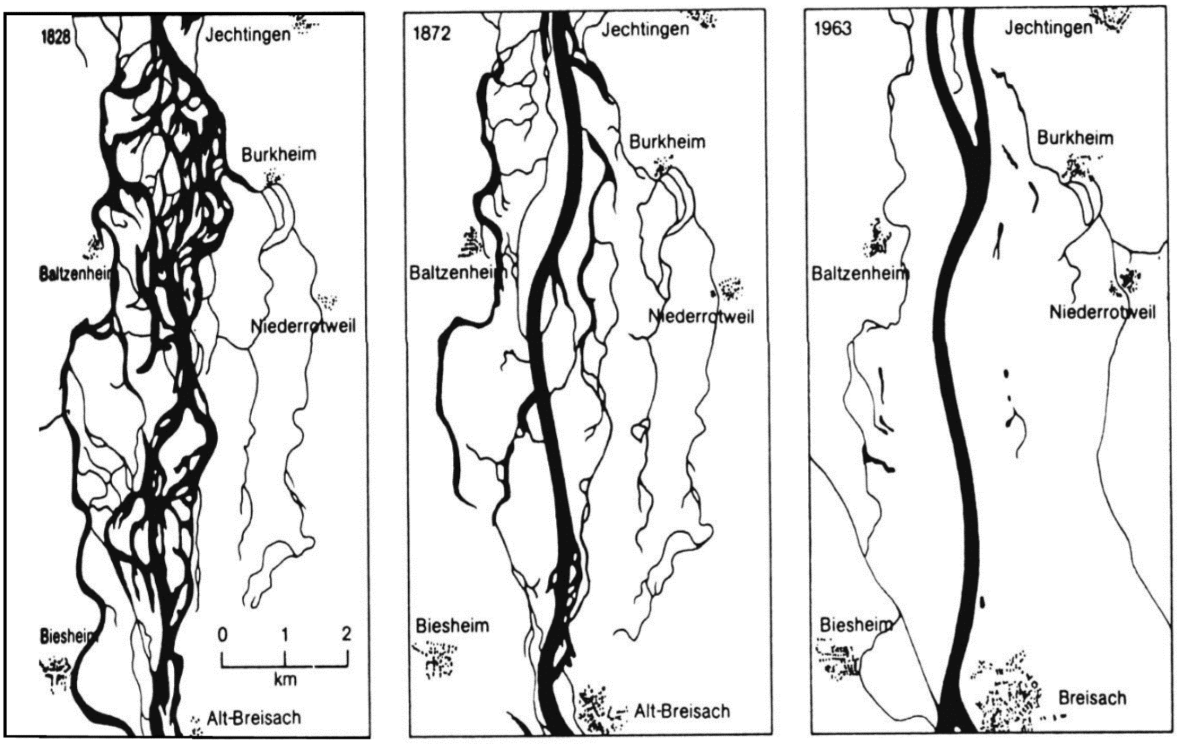


Figure 4.5 The landscape change in the upper Rhine years 1828, 1872 and 1963 (Lozán & Kausch, 1996)

Those three figures above illustrate the landscape along the river how it changed since the year 1828. At that time, there were a lot of small tidal water channels along the river numerous green areas such as islets that split into smaller parts, however, in the year 1963 the development way of the river was crossing the area straight while also having flood bypasses in some areas parallel to the main river. In the past, the river system deteriorated and natural habitat fragments were numerous (UNECE, 2010)[17]. The present improvement of the Rhine River line mainly supports the flow of the river and the river front development.

4.2.2 The room of the river principle on the Rhine River

One important alternative design concept with the purpose of flood management is the so called “room of the river principle” (Dutch government, 2005). The Dutch set up for safety and river flood prevention which concerns the measures of quality spatial planning and maintaining the separation of land and water with high economic benefits (Fokkens, 2006).

The room for the river principle is unique for focusing on both, the safety from flood catastrophes as well as the prosperous environmental atmosphere of the landscape. Those principles will improve the development of a new nature, urban development and the

[17] UNECE (The United Nations Economic Commission for Europe) involving which this research on climate change and environmental policy and the access of environmental information in European country.

restoration of cultural historical values (Nijssen and Schouten, 2012). An important reason for considering these principles is that hard engineered structures are limited in their scalability. For example, it is not possible for dykes to be built increasingly higher, because too high dykes are representing not justifiable high risks in the event of a dyke breach or dam failures.

Therefore, providing the river more room by, for instance, relocating the dykes, excavating secondary channels and even constructing bypasses will enable the river to handle increasing volumes of water[18]. Giving the rivers more room would accommodate climate change effects and simultaneously increase the safety in future flooding. In the following the images represent the measures of this principle in practice.

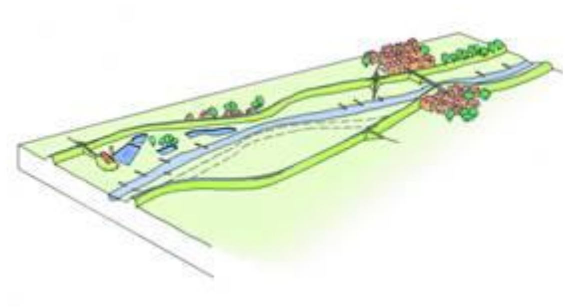
Room for the River principles
(Flood protection & improvement of environmental conditions).

Green river / bypass

Floodplain excavation by removing layers of soil from certain parts of the floodplains, more room is created for the river when the water level rises.

Retention areas (Water storage)

As a result of the controlled combination of a closed flood gate and large volumes of river water flowing to the sea, as the temporary water storage.



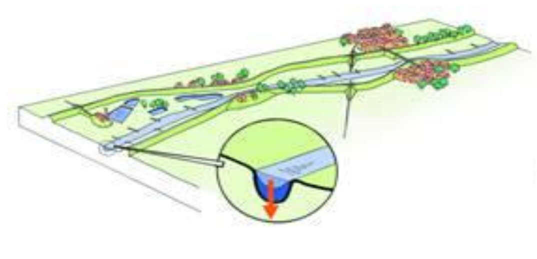
Dyke relocation

Relocation of dykes

By relocating dykes further away from the river, the floodplains become wider, giving the river more room.

[18] Success story of trans-boundary water management in the River Rhine. Anne Schulte-Wülwer-Leidig International Commission for the Protection of the River Rhine (ICPR, 2015b).

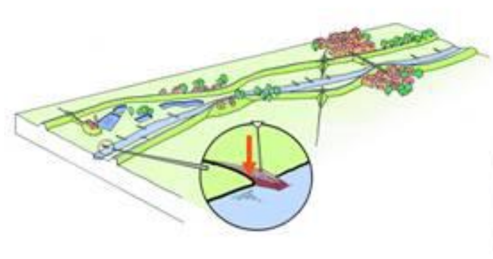
Room for the River principles
(Technological developments)



Deepening summer bed

Riverbed excavation

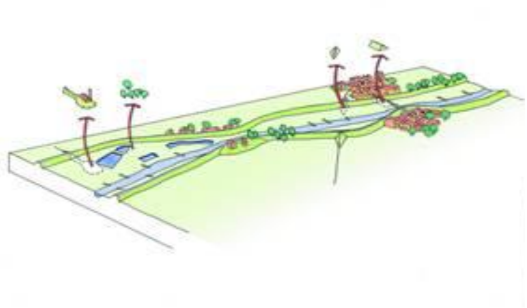
The riverbed is made deeper by taking away the top layer of the riverbed. Because the riverbed is lower, there is more capacity for river water.



Groin Improvement

Lowering breakwater spurs

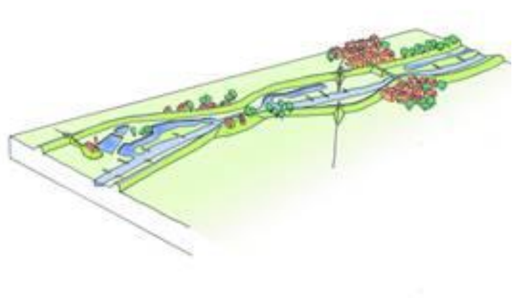
Breakwater spurs ensure that the river does not alter its course or lose depth. However, at times of high water, spurs slow down the flow of the water. By lowering them, the water has a better chance of being transported away faster.



Lowering of floodplains

Depoldering

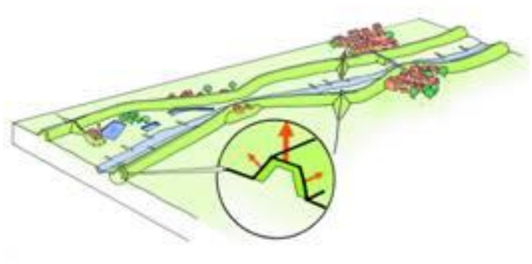
The dyke on the riverside of a polder is relocated further away from the river. This depolders the area and enables water from the river to flood this area at times of high water.



Remove hydraulic obstacles

Removal of obstacles where possible

Removing or redesigning obstacles in the riverbed ensures that the water flows faster.



Rising dykes (When no other option exists)

Strengthening dykes

The dykes are strengthened at a number of locations where making room for the river is not an option.

Figure 4.6 Room for the river principles (Ministry of Transportation and Water Management; Netherland, 2002)

- **Germany/Cologne**

Water retention and land relocation in Germany. For example, there is one water retention project that has been launched in Cologne, because several flooding cases of the Rhine River occurred in the north area of city Cologne. After these floods, the government provided flood retention area. This area can reduce the level of the river by 17 cm (StEB, 2015). This project helps to protect the community of getting flooded in the north area of Worringen, Cologne (Piegeler, 2015). The massive retention area at Worringen near Cologne in Germany is finally completely built up. In 2012 the government decided to create this retention area after they had been planning and discussing for years. For residents who live in those communities – Worringen and Roggendorf/Thenhoven – the agency “Stadtwässerungsbetriebe (StEB) opened an information center, where people can participate and bring questions they have about this project, the female mayor announced to their inhabitants to “use the opportunity for participation” on the project.

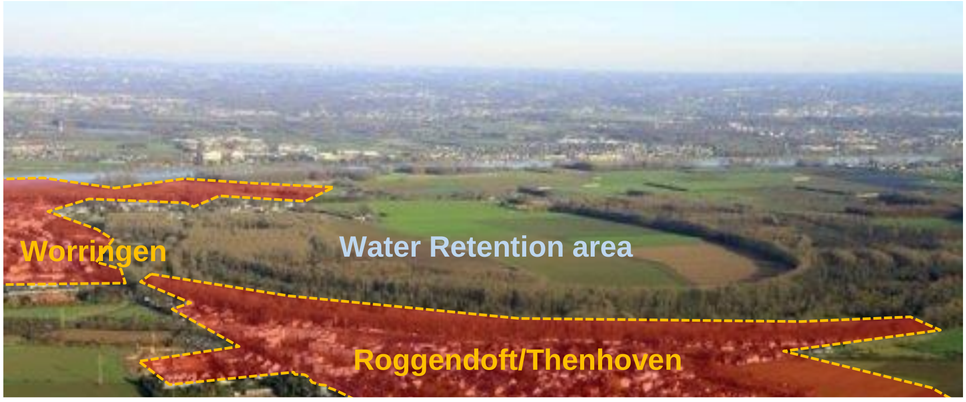


Figure 4.7 The planned retention area at Worringer Bruch (StEB, 2015)

In 1993 and 1995 the cost of flood damage of two huge and severe floods in Cologne was estimated at 85 million Euro. Rodenkirchen near Cologne was under water and also the old city of Cologne was affected. After the floods occurred, the government decided to find a solution to save the city from flooding.

The municipality of Cologne spent the budget of 430 million Euro to protect the city from floods. The project of the past few years include:

- Circa 60 km of dyke, flood wall protection and mobile barrier were built up or renewed.
- Pumping stations in Rodenkirchen, at the Schönhauser Street, and in Niehl were established to push water back into the Rhine River.
- Several water gates were installed, so they can cut off the underground canal system of the city from the river, to prevent the flood from entering into the city.

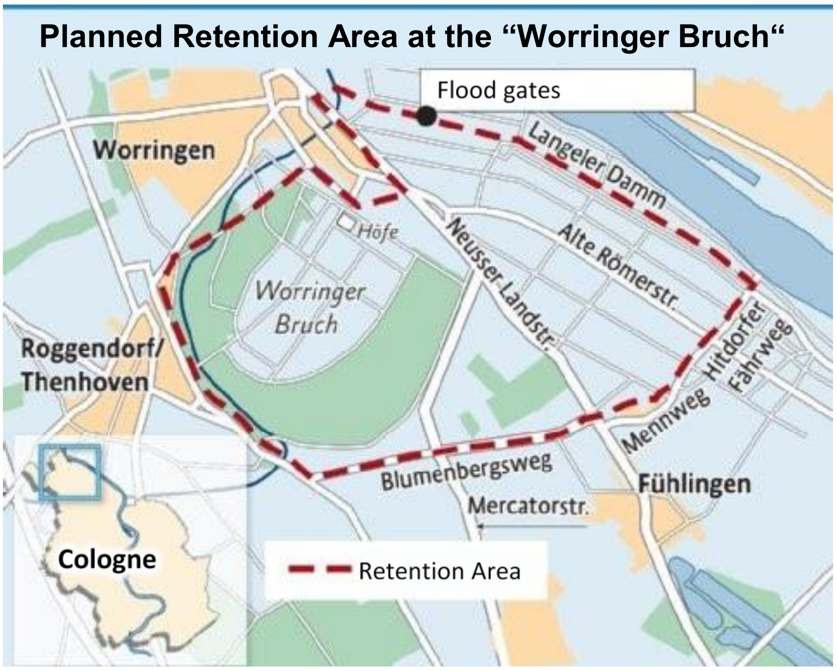


Figure 4.8 The boundary of the water retention area at Worringer Bruch (StEB, 2015)

By now the south of Cologne and the old (inner) city are protected even when the level of the Rhine River reaches up to 11.30 m. The north of Worringen will also save from flooding for levels of 11.90 m.

The most important part of the responsible communities and societies is, to provide their land along the downstream of the river for flood retention areas. In the past, many communities did not agree to have water retention areas which support other cities, however, after those flood situation impacts occurred, the residents changed their attitude, hence nowadays it will be more likely to have water retention area to protect from flooding damage.

Many times water retention areas lead to discussions about the consideration of environmental protection, like in another retention project around Porz-Langel in 2009. However, in the case of Worringen, it was finally possible to achieve an agreement for the retention project.

As mentioned above, this new retention area can reduce the water level of the Rhine River by 17 cm. In addition, by having new dyke-embankments, which will keep back the higher water levels, there will be around 14 more hours to evacuate people from the flood area. Nevertheless, this will only be a benefit for the northern part of Cologne where this project will protect the housings from flood damage.

Likewise, beneficial side effects come along, helping replenish moisture to the soil and filling in water to the groundwater, which helps the agriculture and the forestry (HCK, 2015). And for the city where the land management is well-organized, flood retention will possibly protect human lives and property along the river (EGLV, 2015).

However, water retention areas can lead many people to move from their old housing which leads whole communities to re-settlement or relocation. This topic will explain in condition of Thailand in Chapter 5.4 (The experience of relocation in Thailand)

4.2.3 The Rhine 2020 program on sustainable development

Currently, there are several international cooperating projects on the Rhine River such as the international cooperation on shipping on the River Rhine – The International Commission for the Protection of the Rhine (ICPR). The Rhine River Action Program, which was set up from the year 1987 to 2000 focused on the guarantee of high quality drinking water, reduction of contamination (water pollution), construction of basins for collecting fire extinction water, water & alert systems and ecological rehabilitation. Especially the warning & alert plan at the Rhine River from the Rhine action program is the most important measure for flood prevention (UNESCO-IHE, 2010).

Besides the flood protection program, there are other programs such as the International cooperation on Rhine Ecology, the “Rhine River 2020” and the Water Framework Directive for the natural reproduction of fishes such as salmon which aimed the restoration of their continuity and the optimization of the salmon habitats. From 2009 to present, 5000 salmons have returned to the Rhine. Their expected population will increase in 2020 by about 7,000-21,000 habitants per year (ICPR, 2013)

The future goal of the “Rhine 2020” program concerning the flood protection is heading for three following main measures which will apply an increase of water retention by 1) reactivating inundation areas, 2) strengthening dykes and 3) drafting maps for risks of inundation (for spatial planning).

The actions of the working process will start from integrating data and information. Further, rules of the ICPR (International Cooperation for Protecting the Rhine) will be decentralized and require good political mandate, technical knowhow and funds to become effective practice.

In personal summary, in this section of the research it was found out that the accomplishment of the international cooperation in projects on the Rhine River program is the improvement of flood prevention by using the “room of the river” principle by emphasizing on advancement of environmental conditions concept.

In the specific case of the area of the central region of Thailand, the co-boundaries with many districts along the Chao Phraya River are comparable with the country boundaries along the Rhine River. Although the topographical characteristics of the Chao Phraya River from Thailand are different, the international cooperation as it is applied in the case of the Rhine River can be similarly established as a co-operation between the districts of Thailand along the Chao Phraya River. The cooperation of districts gives the opportunity to share the area for the “room for the river” concepts and de-centralized responsibilities to the organization of the land, water and environmental management.

Thus, the successful co-operation will provide a good opportunity for flood adaptation. Two points which are interesting and seem to be suitable for the central Thai flood conditions are the green river bypass and the water retention. These measures are aiming for living in harmony with the river and having fewer conflicts with the nature while also benefitting the tourism.

4.3 International Cooperation on the Elbe River

In the Elbe river basin, the international cooperation began in 2000 which had an objective on the cooperation framework of the International Commission for the Protection of the Elbe River (ICPER). The main goal of cooperation between countries is to be responsible for flood management and the action plans for the Elbe River basin. Another important group is working together with the European Union and has a project mission on the flood management that is named the *ELLA* project (as mentioned before in Chapter 4.1.2 and 4.1.3). The measures combine flooding prevention with long-term spatial planning along the Elbe River basin.

4.3.1 Physical and hydrological characteristics of the Elbe River

The total length of the Elbe River is 1,094 km from the spring in the Krkonoše Mountains to the North Sea estuary at Cuxhaven, a catchment area that comprises over 148,268 km^2. This makes the Elbe River the fourth largest river in Europe (FGG, 2003).

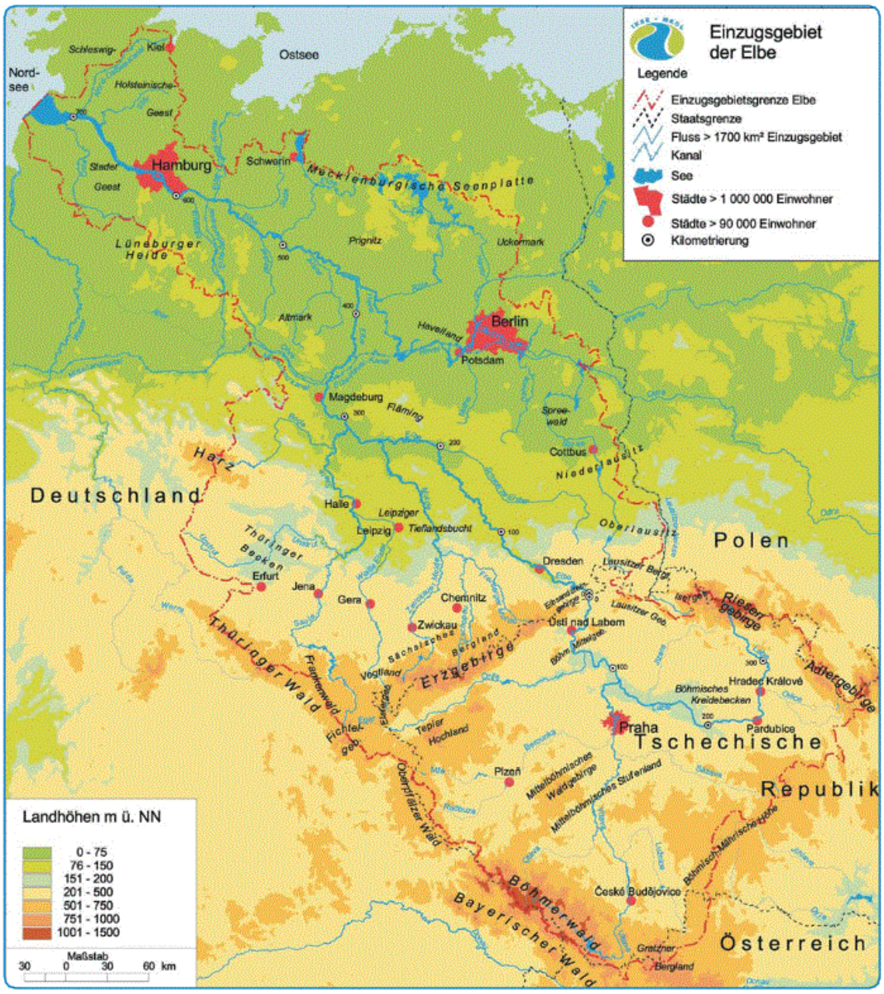


Figure 4.9 Topographical overview map of Elbe River basin (ICER, 2014 p.5)

The river basin covers over four countries, whereas the major part lies in Germany (65.5%) and the Czech Republic (33.7%). Much smaller parts are located in Austria (0.6%) and in

Poland (0.2%). The basin is inhabited by 24.5 million people and has many tributaries including the Vltava, Saale, Havel, Mulde, Black Elster and the Ohre rivers.

Table 4.1 Discharge surface, length and population of the Elbe River (ICER, 2014 p.4)

Surface area: 148,268 km²		
Germany	97,175 km²	65.54 %
Czech Republic	49,933 km²	33.68 %
Austria	921 km²	0.62 %
Poland	239 km²	0.16 %
Length of Elbe River: 1,094 km²		
Germany	727.0 km*	66.4 %
Czech Republic	367.3 km	33.6 %
Population: 24.40 Mio.		
Germany	18.12 Mio.	74.3 %
Czech Republic	6.21 Mio	25.4 %
Austria	0.05 Mio.	0.2 %
Poland	0.02 Mio.	1.1 %

As the table above demonstrates, approximately 2/3 of its river basin belongs to Germany while approximately 1/3 to the Czech Republic. Furthermore, the greater part of the population living along the Elbe River also settles in Germany (74.3 %) and the Czech Republic (25.4 %) respectively. Thereby, the focal point is mainly the Czech-German cooperation and their measures in the Elbe River basin.

4.3.2 The disastrous flooding events of the Elbe River

Throughout history there have been many occurrences of flooding in central Europe. In the period between 1971 and 1995, more than 150 major floods arose in Europe, including several in the trans-boundary area of the Elbe River (WWF, 2002 p.3)[19]. Germany and the Czech Republic, where the Elbe River primarily flows, were also affected on flooding in the years 2002, 2006 and 2013.

According to the Munich Re (2003), the 2002 flood in central Europe was extremely expensive. The caused damage was in the range of 15 billion Euro and insured losses were approximately 3 billion Euro.

This event was the costliest disaster of the year 2002 in terms of economic losses. The largest losses happened in Germany where heavy rains led to some of the worst flooding that Saxony has experienced in more than a century.

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[19] World Wide Fund for Nature (WWF), provided the paper on living Waters Programme-Europe on topic: More intelligent river basin management using wetlands can alleviate future flooding events.

Table 4.2 Costliest floods in recent years (Mechler & Weichselgartner, 2003) (Kron & Thumerer, 2002 p.3)

(Original values in billion US$, not adjusted for inflation)

Rank	Year	Country (mainly affected regions)	Economic Losses	Insured [%]
1	1998	China (Yangtze,Songhua)	31.0	3
2	1996	China (Yangtze)	24.0	2
3	1993	USA (Mississippi)	21.0	6
4	1995	North Korea	15.0	0
5	1993	China (Yangtze,Huai)	11.0	0
6	2002	Germany (Elbe)	9.8	<20
7	1994	Italy (North)	9.3	<1
8	1993	Bangladesh, India, Nepal	8.5	0
9	2000	Italy (North), Switzerland (South)	8.5	6
10	1999	China (Yangtze)	8.0	0
11	1994	China (Southeast)	7.8	0
12	1995	China (Yangtze)	6.7	1
13	2001	USA (Texas)	6.0	58
14	1997	Czech Republic, Poland, Germany (Odra)	5.9	13

From a hydrological perspective, the tremendous flood event in 2002 was concentrated in the Elbe basin on the 13th August 2002 (Meinel *et al.*, 2003), the flood in the state capital of Saxony – Dresden – was recorded to have reached an unprecedented level of 9.40 m in areas where normally the water level is about 2 m.

Table 4.3 Comparison of selected flood levels of the Elbe in August 2002 with historical reference values (Regional Office of Environment and Geology, 2002 p.7.)

Water-level gauge	Record peak (previous value)		Peak flood 16.-18.08.2002 (cm)	Difference (2002 record peak) (cm)
	cm	Date		
Ústí nad Labem (CZ)	1,119	3/1845	1,185	+66
Schöna	868	4/1941	1,202	+234
Dresden	877	3/1845	940	+63
Torgau	863	3/1940	945	+82

In the year 2006, the Elbe River flooded once again, which was caused by heavy rainfall in combination with snowmelt from the Krkonoše Mountains in the Czech Republic, leading to a swelling of the Elbe River to a level of 7.45 m. Many residents in Dresden, Germany, who live alongside the Elbe were forced to evacuate.

However, the historic city, Dresden, whose prized Baroque and Rococo buildings were severely hit by the flood waters in 2002, escaped significant damage in the later 2006 flood.

The German Aerospace Centre (DLR, 2006) prepared flooding areas for the local communities in the Elbe flooding from 2006 which can be used for basic mitigation of flood events and adaptable planning for a better handling of flood situations in the future.

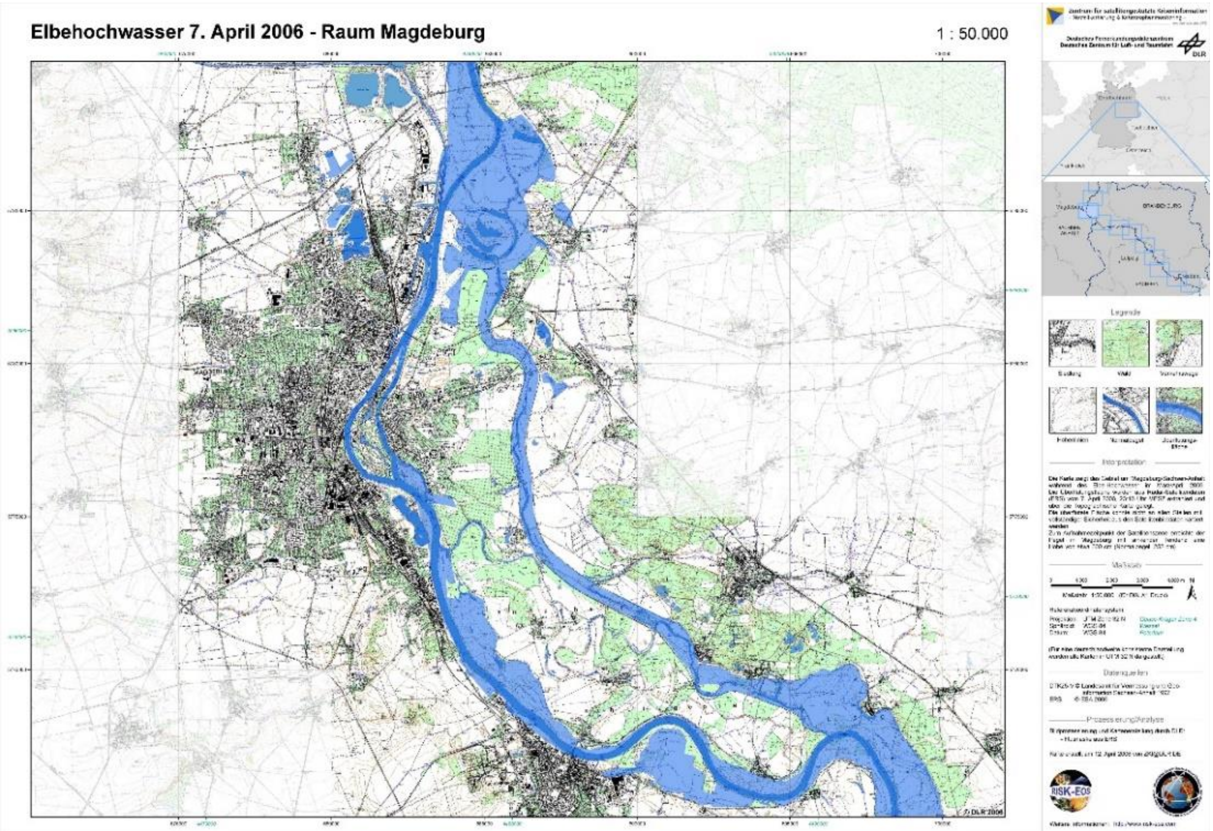


Figure 4.10 Elbe flood 2006: German Aerospace Centre (DLR, 2006)

The DLR prepared satellite image maps of the region in the risk flood areas. The purpose of the satellite image maps is to support all stakeholders and official practice of disaster management.

After the devastation of three floods in August 2002, March/April 2006, and January 2011, the Elbe basin was triggered again by extensive and unusually heavy precipitation from May to June 2013. One major cause of this large-scale flood events were the special occurrences of interactions between the atmospheric and hydrological processes. Low-pressure areas dominated the weather pattern at that time. Numerous precipitations were not the only reason for the flood in the year 2013. In fact, the soil was already saturated and could not absorb more water, which lead to an overspill of the discharge area of the river (FGG, 2003)[20]

[20] Flussgebietsgemeinschaft Elbe (FGG) Elbe catchment 97,000 km² of the approx. 148,000 km² catchment area of the Elbe lies the largest part of the catchment area in Germany.

Meanwhile, the ICPER (2014) reported that the flooding in 2013 was different from other floods that used to occur in the past, because the soil moisture values (wet initial catchment conditions) were higher than in any other flood since flood-recording started in 1962.

Table 4.4 Comparison of flood losses in the Elbe floods in year 2002 and 2013

Elbe Floods	Material damage	Fatalities	Direct federal flood aid
2002	11,710	38	9,000
2013	5,200	15	8,000

The results prove that the loss of lives and material damages from the flood in 2002 to the flood in 2013 reduced along the Elbe river.

In conclusion, comparing the flood situation in Dresden with the inundation flooding in historical sites in Thailand like in Ayutthaya, the situations can be found to be quite similar. To solve the flood problems at the Elbe River, case studies for improvements in the flood management were launched during that time. Furthermore, since the devastating flood in central Europe occurred in 2002, the action plans for the “Floods in the Elbe River Basin” have been created. This is one factor which can prove that the loss of lives and damage are decreasing after having good flood management plans.

4.3.3 Action Plan for the Elbe River Flood Protection by ICPER (2009)

The preparation of the plan was based on the work that commenced within the ICPER framework in the mid 90’s. The following three main elements are included:

- *The flood emergence analysis*
- *Mapping the existing level of flood protection*
- *The flood protection strategy*

During the compilation of the plan, the knowledge and experience that had been gained from the catastrophic flood of August 2002 was utilized.

In terms of the population growth and a change in the hydrological cycle in the future, a good action plan can reduce harm, loss of lives and damage of properties and building material. The action plan on the Elbe river project can also be divided into different duration.

In the year 2006-2008, the plan illustrates appropriately how the effective action plan developed from the first overview from 2003-2005. The action plan (ICPER, 2009) implemented every important pilot project and each working activity for the entire watercourse of the Elbe River such as:

- *Enhancing the capability of the landscape to hold water within the basin, in the river channels, and in the flood land area.*

- *Decreasing the potential of damage in areas at risk, namely by mapping flood risk areas.*
- *Protecting the area at risk of flooding with technical measures (Construction of protective levees).*
- *Informing the public and rising awareness of flood risk.*
- *Enhancing the flood forecasting and warning systems.*

Therefore, all institutions and stakeholders are involved in the flood management. The plan will succeed, when there is a general cooperation with the society which implies a public agreement.

- **Project suggestion by ELLA on preventive flood management measures by spatial planning for the Elbe River basin** (Results and proposed actions)

Originally, the ELLA action plan project has been co-operating with the ICPER on information and consultation. Nevertheless, the ELLA is focusing heavily on the benefit of spatial planning measures and on the following key points (ELLA, 2006 p.12)

1) *Improving the retention capacity of the land in the river catchment.*
2) *Adapting the land use in flood plain areas.*
3) *Suggesting the beneficial usage of the land in disaster areas and sharing information for implementation in the spatial plans.*
4) *Designing extensive retention zones.*

The implementation of information into the primary action plan of the ICPER covered the period from 2003 to 2005. The report lays emphasis on the following topics:

1) *Hazard analysis*
2) *Flood warning and forecasting system*
3) *Measures for the improvement*

Thus, it should be noted that the main task of the EU water policy and the European Spatial Development Perspective (ESDF) is to comprehensively combine the available flood managements. The implementation of interesting strategies of the ELLA project – vertical approach from European level to the level of the individual citizen – is beneficial for the flood management (As mentioned before in figure 4.2 ICPE and ELLA strategies; Top-down policy)

The project is trying to have the top policy from the EU regions while cooperating with the ICPER. Additionally, many ministries and German federal states support the laws and regulatory framework and the region level supports the administrative flood protection strategy (bottom-up strategy). Combining both policies (bottom-up and top-down) creates a well-working flood protection cooperation.

4.3.4 **Strategies and concepts on the Elbe flood projects** adopted by the German federal states and the Czech Republic

The working group of *the Federal States on Water Issues* (LAWA, 2006)[21] is one section that launched strategies and programs. This group also adopted water issues and flood control concepts in Germany. Mostly, these projects focus on the role of *spatial planning* in connection with *preventive flood protection measures* for flood risk areas. Those strategies and concepts are adopted by the German federal states, which consist of every state that is located along the Elbe River in Germany such as Saxony, Saxony-Anhalt, Brandenburg, and Thuringia.

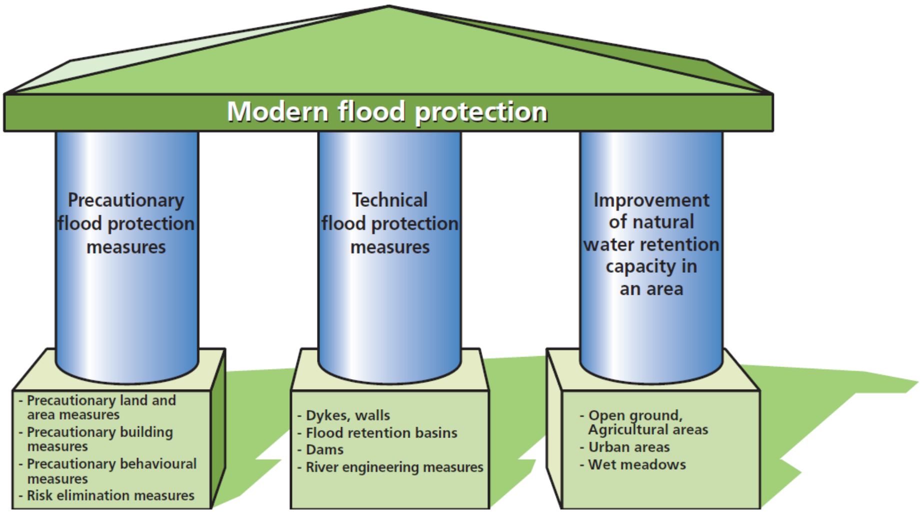


Figure 4.11 Flood protection measures and the relationship of the program of the State of Saxony-Anhalt (ELLA, 2006 p.24)

Ministry for Agriculture and the Environment of the State of Saxony-Anhalt (2003): Flood protection programme of the state of Saxony-Anhalt until 2010, Magdeburg.

Moreover, from 2003 until 2010 the environment protection program of the ministry of Agriculture of the state Saxony-Anhalt has developed the measures which include the Elbe Flood Action Plan and the International Commission for the Projection of the Elbe River.

The modern flood protection is consisting of three main concepts: the precautionary flood protection, the technical flood protection measures and the improvement of the natural water retention capacity in some areas. These concepts will mostly cover the necessary activities to be able to deal with flood situations in the future.

One experience is shown by means of the Talsperre Krebsbach; Thuringia, Germany, which old reservoir (0.43 Mio. m^3) was dismantled and turned into a new river. The construction took place from 1962 until 1964. Problems in the structure of the dam like leakage occurred which had to be maintained.

[21] The German Working Group of the Federal States on Water Issues (LAWA). The LAWA was set up in 1956 Responsible for water management and water legislation which the Federal Government represented by the Federal Environment Ministry.

This led to high costs and possible risks for citizens who are living in the downstream area, which made the reservoir not economically viable and safe anymore. In the past, the dam was used for the generation of electricity, but nowadays the use case changed to a recreation area with sport activities such as swimming and fishing.

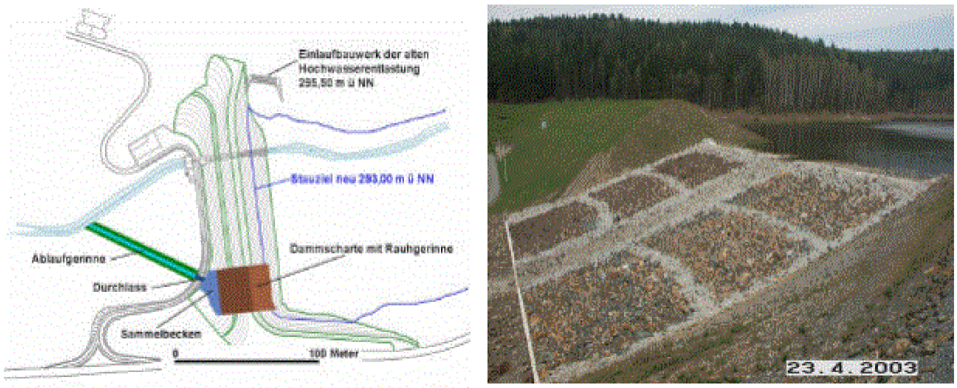


Figure 4.12 Location and view of the provisional flood relief after partial slitting (Mehlhorn, Ottenbreit & Walter, 2003 p.10)

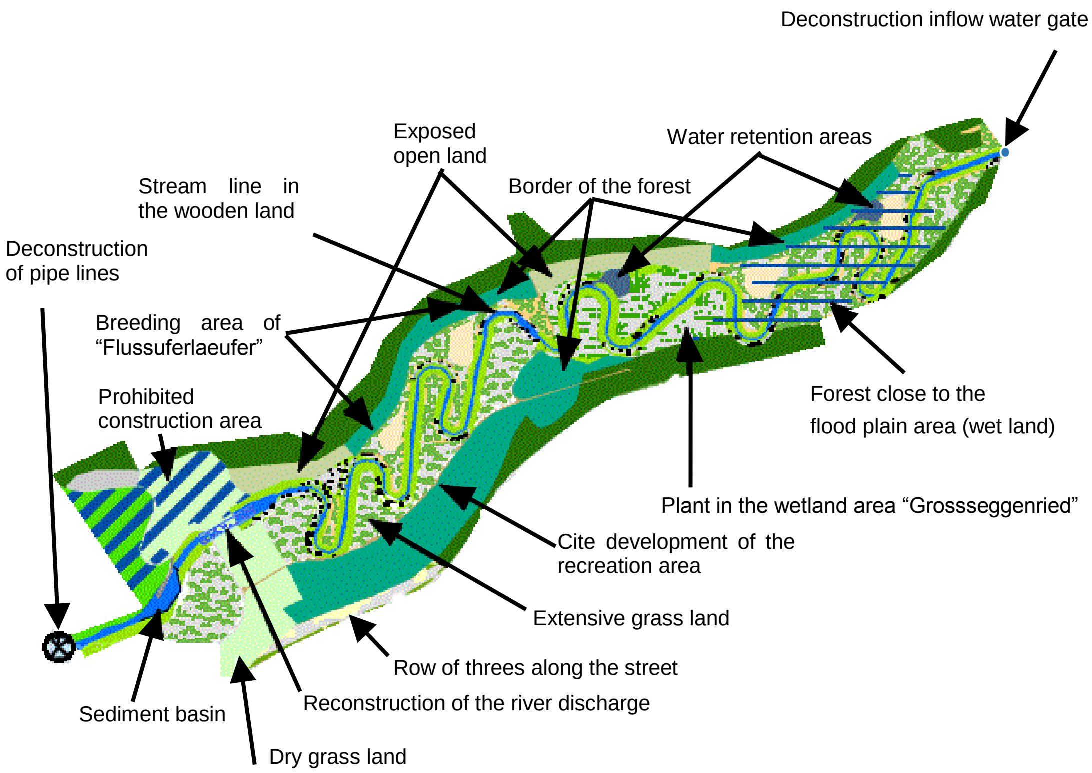


Figure 4.13 Spatial plan and landscape management (Mehlhorn, Ottenbreit & Walter, 2003 p.16)

(The actual river channel was constructed slightly different from the plan in the picture and is approx. 1.46 km long; measurement from 2009 Google Maps data)

The demolishing of this dam will re-build the nature again (Renaturierung)[22] for the community and will benefit the flood protection area. The design plan includes the new river, extensive green areas and water retention.

4.3.5 Spatial Planning Activities

The LAWA (2006) project suggested the following possible actions with the reference to spatial planning in various spaces of the river basin:

(A) Protection of existing retention areas
(B) Redevelopment of retention areas
(C) Retention of rainfall catchment areas
(D) Reduction of damage potential
(E) Technical flood protection measures

The technical flood protection measures (E) which are used to determine hazard zones, are using the “matrix for determining hazard zones” in their calculations.

This matrix classifies the intensity of a flood based on the level of the water depth, the water velocity and the repeat interval. LAWA suggests the user how to adjust for specific conditions in different areas.

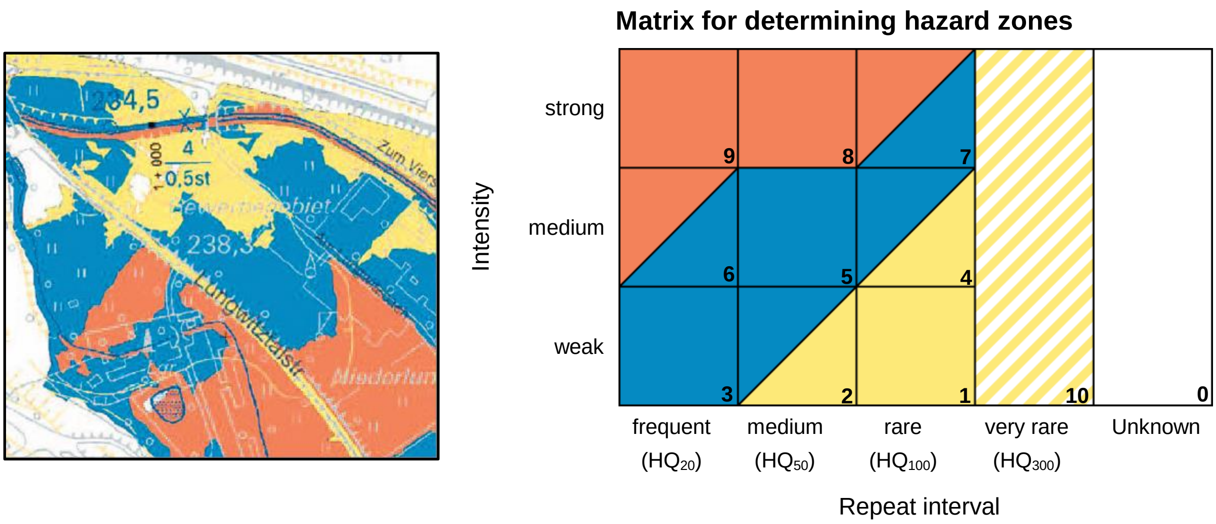


Figure 4.14 Hazard categories (LAWA, 2006)

Based on the interplay between probability (horizontal) and Intensity (vertical); Categories: high (strong), medium, low and very low

[22] Renature is the process of ecological re-building of an area in the sense of a natural habitat which is in harmony with the wildlife, humans and communities, while furthermore supporting flood protection.

There is a variety of actions on different intensities that the program will suggest:

- High intensity refers to (a) settlements of humans and animals which will be at risk in their shelters and/or (b) where buildings may sustain damage or be destroyed.
- Medium intensity refers to (a) a risk for humans and animals outdoor (while indoor they would only experience residual risk, and/or (b) buildings may sustain damage.
- Low intensity refers to a setting where (a) human and animals are both located outdoor and they only incur residual risk indoor, and/or (b) some parts of buildings such as basements may sustain damage.

In addition, the physical parameters for qualitative classification of the systems can be modified for displaying all kind of circumstances in the flood hazard zone.

Table 4.5 Examples of intensity classifications

Intensity	**Flat area**	**Steep area**
	Water depth (h)	**Water velocity (V)**
High	>2.0 m	>2.0 m/s
Medium	0.5 to 2.0 m	0.5 to 2.0 m/s
Low	<0.5 m	<0.5 m/s

Some areas of flood plain bases are considered for resisting a flood level of a 100-Year-Flood (HQ_{100}). When, the flood level is higher than the level of a 100-Year-Flood ($>HQ_{100}$) the area is specified as a risk zone area (ibid).

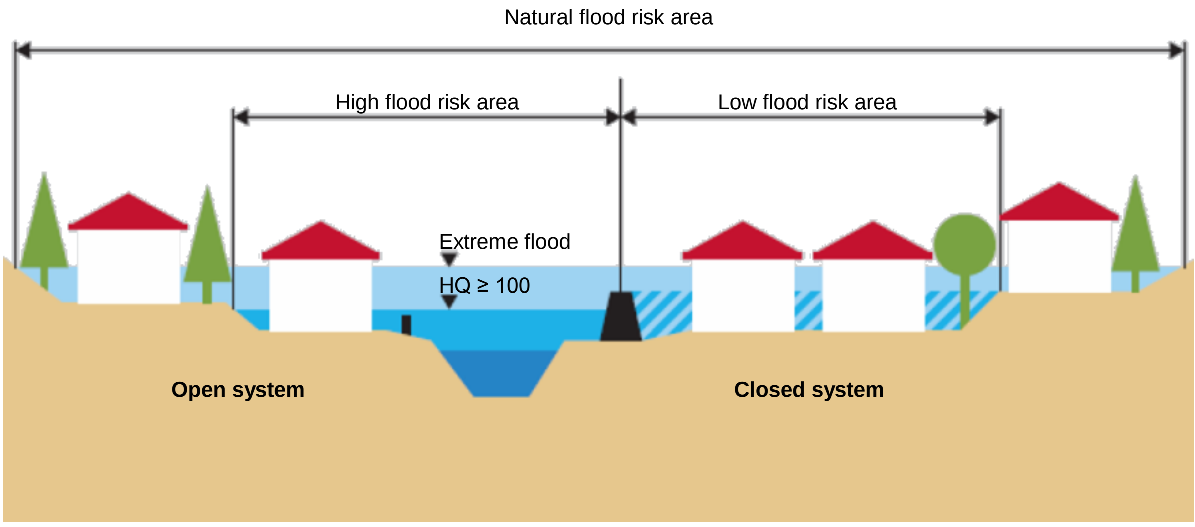


Figure 4.15 LAWA terminology on flood risk area (LAWA, 2006 p.41)

The Federal Water Act (WHG) states areas with a statistical recurrence of flooding exceeding in 100 years as flood prone areas (ibid).

To sum up the LAWA work on flood hazard zones and risk management, the data from the historical record of frequency and precise of flooding are the most significant for allowing to prepare the flood plan, making the flood protection and adaptation on a new human settle and emergency evacuation for the community.

4.3.6 Summary of the international cooperation on the Elbe River

The international cooperation on the Elbe River is mostly connecting the EU policy and the law and flood planning regulation of each country and is a member in the EU flood risk management. The countries participating in the Elbe River cooperation all have standards for the spatial planning and the basic data sources. These standardized base maps can be used for preparing the flood risk maps and the land use guidelines. The combination of flood mapping in practice and the conservation of open space for the river will be beneficial for reducing severe floods in the Elbe basin regions. Developing green space areas along the Elbe River with water retention areas provides the key option to broaden the full potential of the spatial planning at the Elbe River.

As the benefit from cooperation, Thailand can apply the integration of the spatial planning by linking flood management and human settlements and space activities along the Chao Phraya River. The main advantage of the integration will be an improved emergency plan for flood evacuation, well-organized land use zoning and safety housing in flood risk areas by enacting the building code and the regulation for the communities. The organizations which are responsible for the Chao Phraya River management should have the response of providing the standard for base maps which all organization have to use. The cooperation of organizations will greatly improve having maps with the identical standard before the in-detail planning of the flood management project starts. Although, some data in the design and the planning may be different in each authority, the basis on a standard geo-referencing framework should be set of standard elements. Therefore, the mapping data base will excellently be useable for the flood data management system. The local municipalities will be able to select suitable developments to avoid conflicts in the planning due to mapping differences and overlapping work responsibilities.

4.4 International Commission for the protection of the Danube River

4.4.1 Characterization of the Danube River Basin

The Danube River Basin is the largest river basin in the European Union and the numerous of international rivers in the world involving 19 countries such as Austria, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Germany, Hungary, Moldova, Montenegro, Romania, Serbia, Slovak Republic, Slovenia, Ukraine and some small territories in Danube Basin - Switzerland, Italy, Poland, Albania and Macedonia. The river basin covers 801,463 km^2 and has the length of 2,860 km. The Danube begins in the Black Forest in Germany, and flows predominantly in the direction of south-east ending into the Black Sea. The Danube Delta is a unique World Nature Heritage Site. The entire protected area covers 675,000 ha (1 ha = 0.01 km^2) and includes extensive flood plains with more than 600 natural lakes and marine areas. (ICPDR, 2004)

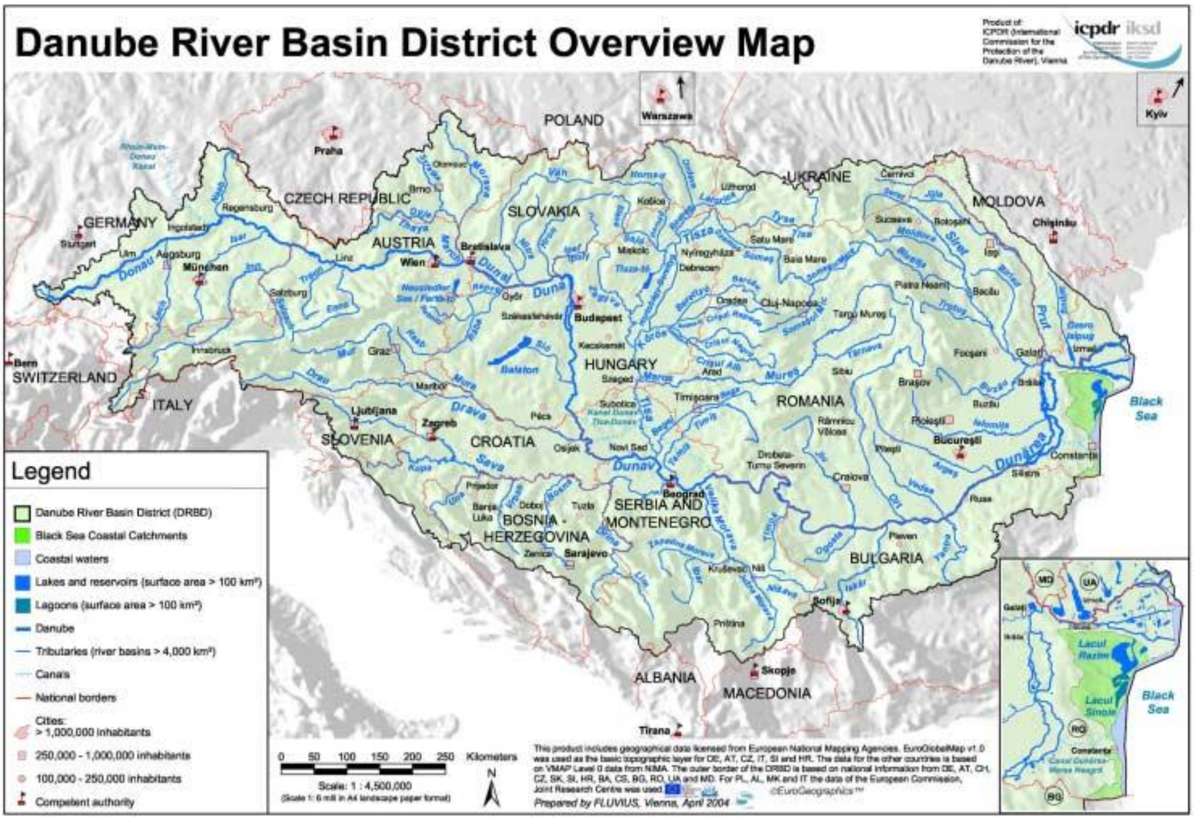


Figure 4.16 Danube River Basin on The EU Water Framework Directive (ICPDR, 2004 p.9)

One main cooperation is the International Commission for the Protection of the Danube River (ICPDR)[23] in cooperation with the countries of the Danube River Basin. Mainly, the mission is concerning to promote and coordinate sustainable and equitable water management, including conservation, improvement and rational use of waters for the benefit of the Danube River Basin countries. Great flood events in the Danube River Basin of have occurred in 2002, 2005, 2006, 2009, 2010, 2013 and 2014.

4.4.2 Flood situation in Bavaria, Germany

This section will focus on the flood experience from the Danube River about some events in Bavaria, Germany. Firstly, a case from the Inn river in the area of Simbach is mentioned (The confluence of the Inn river and the Danube is in the area of Passau in the South of Germany).

A flash flood occurred in the area of Simbach, which was caused by blockages. Secondly, the 2013 massive flood in the Tegernsee, Rosenheim and Deggendorf-Fischerdorf area is shown which involves a solution for the Bavarian future plan on flood management.

[23] The sustainable management of flood risks is one of the actively key works for ICPDR.

- **The obstacle of flood drainage**

(A) Flotsam; Driftwoods and other materials *(Treibgut)* can block the water flow during flooding. For instance, in a flooding situation blockage was found in spaces as such the riverbed, the coastline, the foreshore and in the dam water-gates (Tide-gauge) (Patt & Jüpner, 2013).

Flotsam can be roughly divided into three groups of blockages (three origins of floating debris):

1) Trees in the river resulting from landslides or erosion in the root zone of the tree (Bank or foreshore).
2) Floodplain supports or secondary material (lumber, bulky waste, especially motor vehicles).
3) Parts of damaged facilities such as stationary buildings, sheds, bridges and others.

Many buildings and facilities have damaged when they are hit by flotsam (Treibgut). A massive flotsam collection at water gates and bridges damages the construction and in some cases even brings them to collapse.

In some areas where the water stream situation is suitable for blockage gathering, hundreds of square meters of driftwood can be found. These massive collections are caused in first place by narrow parts of the river or water gates. This leads to an increase of severe floods in that place or the foreshore. Furthermore, the driftwood gatherings are getting even bigger by carrying even more flotsam to that area. Mostly those new flotsams are coming from train track dams and street dams. Electric lines or pipes under bridges often catch that flotsam when the river reaches a high-water level.

After a flood, the first action should be taken is to collect the flotsam from the river. This action can usually face difficulties, but anyway, this action has to be taken as soon as possible to reduce the flood level quicker.

In the future, new bridges have to be well-designed, so flotsam will not gather at bridges and cannot affect the water run-off like in the present situation.

(B) Simbach; One example where a district in the south of Germany was confronted with a flood situation from the river Inn, one of the estuaries of Danube, in 2016. Blockage lead to massive flooding in the nearby community. The German newspaper Süddeutsche (2016, June 10) reported that a blocked pipe seemed to be the main factor causing a dam failure. The extreme rainfall within a few minutes was creating a huge lake at the dam. The blocked pipe therefore did not make a fast-enough runoff possible.

According to another newspaper, the Bayerische Rundfunk 24 (2016)[24], the cause of the flooding on the first of June 2016 were heavy rainfalls in the area around Rottal-Inn. This lead to flotsam blocking pipes to a certain degree, which lead to such a high pressure on the dam that it finally broke down. The water masses and the debris flow then even cut the road.

[24] BR 24 is one of the online news services of the Bavarian television company, Germany.

The pictures below represent the situation:

(A) (B) (C)

(A) Debris flow blocked the water drainage during heavy rainfall.
(B) The pipes were blocked from the debris flow.
(C) The road was cut by the heavy pressure of the water.

(Photos from Harald Mitterer, Andreas Wenleder und Uli Scherr; Date: 09.06.2016)
(Bayerischer Rundfunk, 2016)

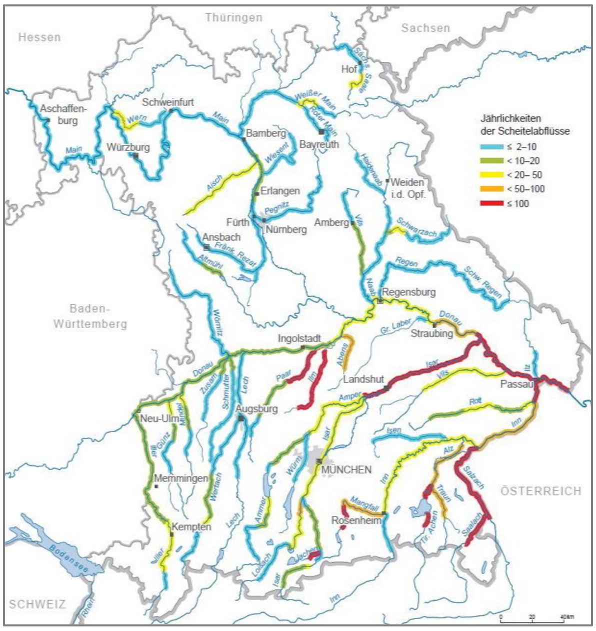
(A) (B) (C)

(A) The flood from 1899 in the same city.
(Photo from the book „Unser Simbach“ from Rudolf Vierlinger)
(B) The „Innbrücke“ (Inn bridge) during the flooding in 1954 (Photo from Lehner)
(C) Flood in 2013

The flood of Simbach, is one important case of a city that faced with many floods for many years already in the past. It is no new situation for the local people. However, the loss of lives due to human made structures is a new factor. The city is located in a heavy rainfall area and furthermore in a cross section of water flows. In the future, those points will be in discussion of how to prevent flooding more successfully in the city. And for years agriculture was focused on corn - leading to soil hard like concrete, preventing infiltration.

4.4.3 Flood June 2013 Bavaria, Germany

Flooding in Bavaria[25], Germany has been recorded in 1988, 1999, 2002, August 2005 and June 2013. Especially, in 2013 a massive and catastrophic flood occurred with damage in the whole Bavarian State with costs of approximately 1.3 billion Euro. (Bayerisches Landesamt für Umwelt und Verbraucherschutz, 2015).



Area: 70,548 km^2
Location: In the southeast of Germany
Population: 12,843,514 inhabitants (31st Dec 2015)
Density: 180/km^2
Capital city of Bavaria: Munich
Major River: Danube and Main River
(Bayerische Staatsregierung, 2016)

Figure 4.17 The Danube River in Bavaria

The length of the Danube River in Bavaria is 368 km. The drainage area is approximately 48,200 km^2 while the population is 8.5 million large around the main southern tributaries: Iller, Lech, Isar and Inn. Most important lethal tributaries are: Wörnitz, Altmühl, Naab and Regen.

(A) (B) (C)

Figure 4.18 Flood 2013 in Bavaria, Germany (LfU, 2013)

(A) Tegernsee, (B) Rosenheim, (C) Deggendorf-Fischerdorf

The Bavarian State Ministry of the Environment and Consumer Protection (2014) constituted a strategy and solution for catastrophic floods, called Action Program 2020, which improves

[25] Göttle, 2015 Winter Semester Lecture, TUM 2014- 2015 and LfU, Bavaria, Germany

the flood prevention in Bavaria, Germany. After the enormous flood in June 2013, they updated their Action Program 2020 and the flood prevention strategies are now following the Action Program 2020 plus.

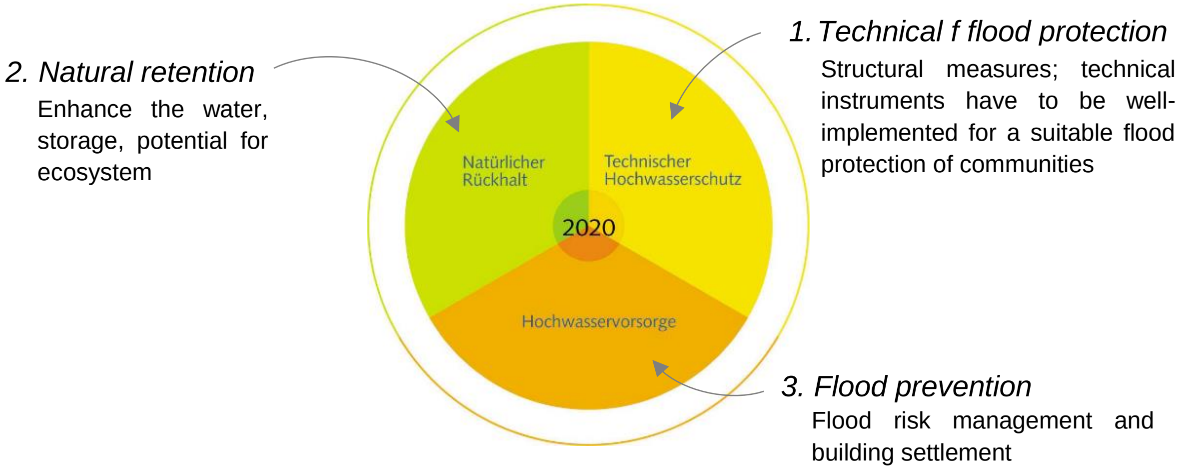


Figure 4.19 Flood protection Action Program 2020. Bavaria, Germany (The Bavarian State Ministry of the Environment and Consumer Protection, 2014)

1. *The measure of natural retention*

   The main reason why floods are occurring is when the rain cannot infiltrate into the ground. To avoid this, these methods are possible:

   (1) Support the infiltration of the rain water
   (2) Adapted land management and land use
   (3) Renaturation of rivers
   (4) Dyke displacement
   (5) Renewal of protective forestry

2. *Technical measure of flood protection*

   Fundamentally, to solve flood problems in the long-run, natural management cannot be the only measure to sufficiently protect the community.

   Technical protection measures like dykes, walls or storage facilities are generally indispensable. Possible technical tools are:

   (1) Water area *construction*, for instance, dykes, flood wall protection and mobile flood barriers (Mobile protective equipment)
   (2) Tidal pools or canals around the city or along the river for keeping water (Flutmulden)[26]
   (3) Improvement and retrofitting of existing flood protection facilities
   (4) Technical support through reservoirs, dams, flood polders.

[26] A flood trough ((Flutmulden, Tidal pool is a ditch), which has been dug around a city, for example, or has been created by embankment and is intended to protect it against severe flooding in case of a flood. This type of flood protection is one of the technical aspects of flood protection

3. *Flood risk management measures*

   (1) Keeping flood risk areas clear from human settlements (Buildings)
   (2) Adapting construction measures for building so that they experience less damage during flooding.
   (3) In case of flood damage, the flood insurances have to be prepared with emergency plans.
   (4) With early enough warning and information, the damage can be reduced.

Those are the actions from the flood Action Program 2020 which are a big step towards in reducing the flood risk in Bavaria. Those actions have been further improved in the Action Program 2020 plus.

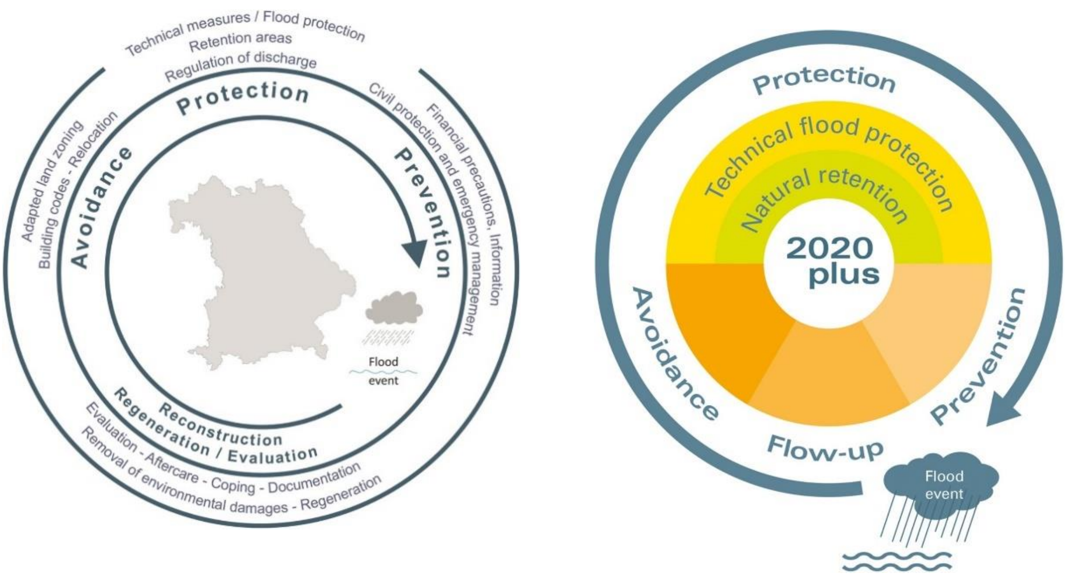


Figure 4.20 The Action program 2020 plus (The Bavarian State Ministry of the Environment and Consumer Protection, 2014 and DWA, 2016)

The program consists mainly of seven points which the program plans to achieve:

1. To avoid damage as same as to avoid hazard areas. This can be achieved by preserving an area where flooding is often occurred solely for the flooding water and keep that area clear from buildings.
2. Flood protection begins with every individual case. During a massive flooding event, the local government cannot guarantee to manage the situation for the whole community on its own. Therefore, the residents should begin with the first steps of protecting themselves and their family members.
3. The flood protection is a common task and therefore every authority should communicate and work together so no overlapping work tasks come up.
4. Depending on the location and the circumstances, the flood protection has to be developed individually. There is not only one solution to fit all the problems. The development of a suitable flood protection is happening step by step and gets improved over time.

5. Flood protection has limits. Due to the changing flood situation, even the best flood protection can face with failures or unpredicted situations in the future.
6. Flood protection provides the aspects of synergy (cooperative interaction) from the flood prevention measures together with re-nature concepts, conservation of nature and the positive aspect of water ecology.
7. Flood protection is a continuous work where the measures have to be monitored, maintained and improved continuously. The strategy has to be improved on up-to-date data, and knowledge.

In summary, the main improvements of the adaptation towards the Action Program 2020 plus are:

1. More budget to support actions, measures and the fast implementation of flood protection in the entire Bavarian State.
2. Acceleration of law procedures and awarding of contracts
3. Technical and strategic updates, for example extending the concept of natural reservation *(“Natürlicher Rückhalt*”), retention concepts, risk analysis and creating more resilient and resistant protection systems.

It is relevant for Thailand to apply the flood and land use planning of Germany, which is listed below.

Table 4.6 Sustainable water management in Germany (Strobl & Zunic, 2006)

Regionalism principle	Regional Resources and habitats have to be protected. Environmental externalities should be avoided.
Integration principle	Interest of the water management have to be integrated into other political concerns.
Polluter pays principle	In the case of pollution or contamination, the costs are passed on to the polluter.
Cooperation and participation principle	In terms of decisions in the water management, all interests have to be considered. The ability of self-organization should be supported.
Resource minimization principle	The active and passive consumption of resources and energy by the water management has to be avoided.
Precautionary principle	Severe damages and unknown risk should be precluded.
Source reduction principle	Emissions of harmful substances have to be prevented on site.
Reversibility principle	The modification of the methods of the water management should be possible. Whereas the impact has to be reversible.
Intergenerational principle	The observation period in terms of plans and decision in the water management sector should be within the period of possible impacts.

In my evaluation of the Action Program 2020 in Bavaria is that in regard of reducing flood problems in the long-run in Thailand, flood protection has to be improved with natural measures and technical supports. Nevertheless, in comparison of the technical supports in Thailand and Germany, the level of quality and the distribution of responsibilities are still challenging tasks for the setting standard of quality and safety.

4.5 New attempts on a new artificial river

The Vienna Danube regulation (Vienna, Austria). The New Danube (German; Neue Donau) is a side channel on the eastern side of the Danube in Vienna, Austria. It was created to provide flood relief by containing excess water.

The Danube Island (Donauinsel), separates the new waterway from the main channel of the river and is made out of the removed material from the newly built waterway.

The project was referred to by the United Nations Human Settlements Programme (UN-HABITAT, 2007)[27] as the "first truly multipurpose fully sustainable flood protection scheme".

Background

The new Danube project is located in Vienna, Austria. The project can be divided into different parts of the management process, which took place in two time periods. The project started by building the first major flood protection – the dam project which forced the river to run into a canal that is passing through the city. The time of construction took from the year 1870 to 1875. This project was required constantly throughout the last hundreds of years.

The second part of the project is the new Danube (Neue Donau; Seitenarm zur Donauregulierung), which was constructed for 16 years (1972-1988) and has a length of about 21.1 kilometer.

Objectives of the Project

The purpose of the project is flood protection measures for the old city of Vienna. By creating a new artificial river and extensive flood controlling engineering, this project made it possible to reduce a massive amount of flooding water using these kinds of drainage function.

Historical Floods

Formerly, the Danube River had many rich branches which are clearly visible on the picture below. Apart from the actual Danube current (today's Old Danube), the Danube in Vienna was spread over an eight-kilometer-wide wetland (Vienna government, 2015).

[27] Flood Control on the Danube in Vienna, Austria – The Danube Island Project, 2006 Best Practices Database, The United Nations Human Settlements Programme, 2007.

Figure 4.21 The Danube excavation plan in 1870-1875 in a contemporary presentation

(Left) Vienna and the Danube from the Joseph II land survey in 1790 (Right)

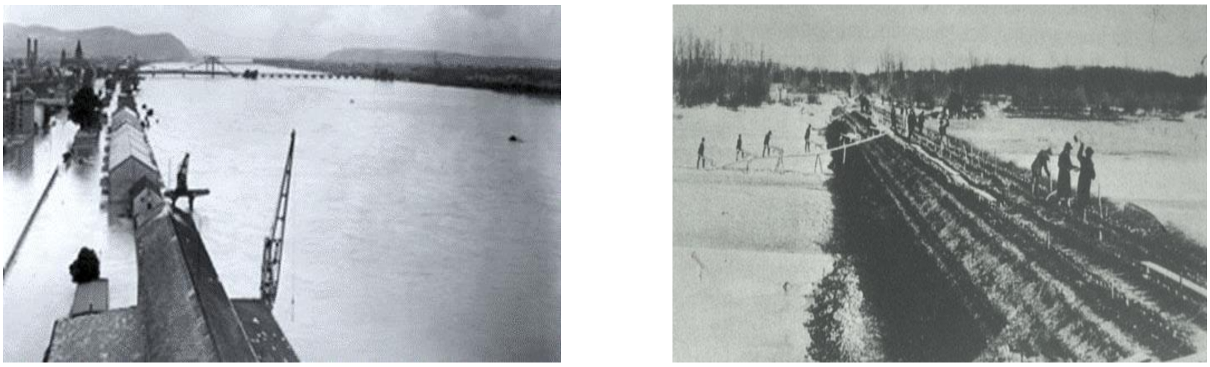


Figure 4.22 Flood in 1954, Vienna (Left); Dam construction from 1870 to 1875 (Right)

Due to a huge flood in 1501, with a water discharge capacity of around 14,000 cubic meters, the flood protection plan started to be considered. The idea of creating a canal for the Danube, which will cross the wide wetlands without letting the river spread all over that area, began to be put into practice in the years of 1870 to 1875 (ibid).

The aim was to prevent floods in the areas around the Danube River such as the three villages (Jedlesee, Floridsdorf and Stadlau) which had been flooded many times in the past. After finishing the project of the new Danube, the risk of being inundated by the floods of the river have been reduced particularly. Nowadays it also benefits the shipping and transportation route.

<u>Better Planning and Design</u>

The first proposal had many suggestions how to achieve neccasary improvements in the case of flood protection. One concept was the construction of the new Danube River.

Table 4.6 Overview of major flood events (Vienna government, 2015)[28]

Flood Event (year)	Flow Volume in cubic meters per second (m^3/s)	Comparable high water level at Reichsbrücke (meter)
Flood 1501	14,000	10.30
Flood 1899	10,500	8.66
Flood 1954	9,600	8.61
Flood 1975	8,560	8.04
Flood 1991	9,600	8.00
Flood 2002	10,000	8.63

In 1954, a big flood catastrophe occurred in Vienna, where the dams of the canal were not able to restrain the flow capacity of 9,600 cubic meter per second. This situation brought the topic of an additional flood protection option into discussion once more and finally led to the decision to construct it in 1972.

The following four concepts of additional options of flood protection were considered:

Option 1: Build up the dam so it is higher than the previous one (Concept idea from the "Bundesstrombauamt"; Administration of Inland Waterway (Austria).

Option 2: Flood way concept. The concept idea was presented by Prof. August Zottl (Hochwasserentlastungsgerinne im Überschwemmungsgebiet).

Option 3: The concept of a bypass river, which lets a noticeable amount of water bypass Vienna in the north-east of the city (Concept by Ewald Liepold).

Option 4: Extending the flow of the river by having a larger area to keep the water. This can also be beneficial to produce electricty with water power plants (Concept provided by The Design Research Association Klosterneuburg; Entwurf Studiengesellschft Klosterneuburg).

However, option No.3 and option No.4 were not considered because those two projects would have consumed excessively time for their construction and required a big budget. As a conclusion, option No.2 was selected and accepted to be the suitable flood protection project for Vienna.

[28] Vienna Government provides the vienna information conserning eduacation & reaserch, transportation & urban planning,etc.

Figure 4.23 Danube Island

(Left) The construction site operated for sixteen years (Right) Aerial view of the Donube Island on final stages (Donuainsel)

Since Vienna exists, it had to face with many floods; hence, in 1870 the Hubertus-dam was built. Nevertheless, shortly afterwards it turned out that there was not enough protection against huge floods. So that, they started building the Danube Island in 1972. After 16 years this massive project was finished.

River regulation, urban development and the construction of a hydroelectric power plant have considerably changed the ecological condition of the Danube section in Vienna (Chovanec et al., 2003).There were considerable changes to the Danube River in Vienna in 1997. Due to these changes there was a plan that was implemented that would increase the natural shoreline to a more reconstructed shoreline that would function better with increasing demands. These plans created more biodiversity and habitat. Multiple species were also introduced to further facilitate the growth. Studies have shown these steps can work to dramatically improve ecologically degraded areas.

The new artificial river protects Vienna from flooding by providing a huge water stream as a second river. The excavated material of this second river was used to build the artificial island. In the summer of 2013 the performance of the artificial river was proven in a one-hundred-year flood (HQ100) where the river had to carry 11,000 m^3 of water per second instead of 2,000 m^3/s. This project helped to protect the city Vienna and the sub-urban areas from flooding (Vienna government, 2015).

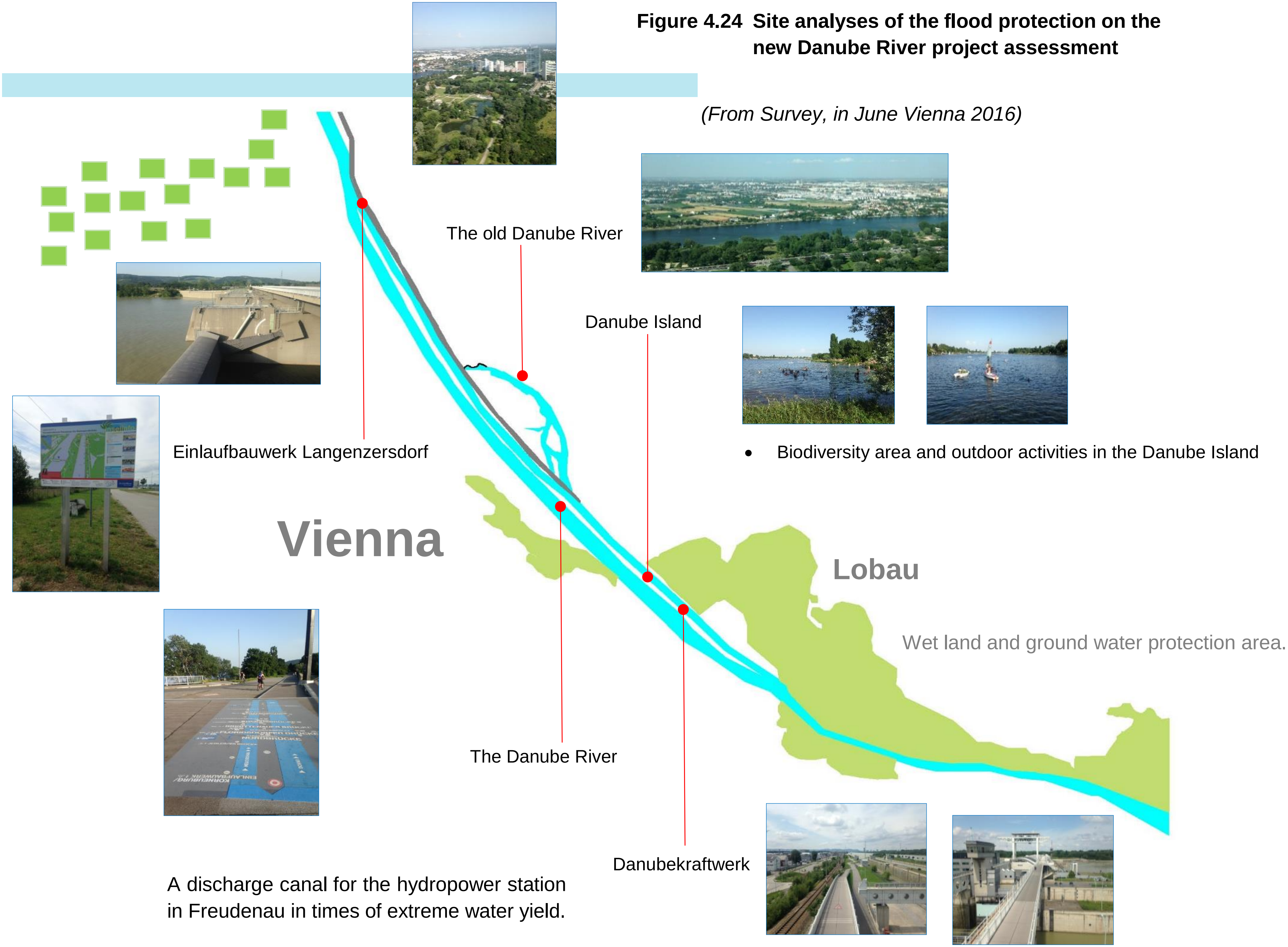


Figure 4.24 Site analyses of the flood protection on the new Danube River project assessment

(From Survey, in June Vienna 2016)

4.5.1 The new Danube River project (Entlastungsgerinne)

The main purpose of the Danube Island (Vienna government, 2015). In term of constructive engineering.

The island´s main aim was for flood protection, however, nowadays it is a very interesting area for tourism, used as a leisure and recreational area for Viennese and other neighboring people from the countryside and one of the most exclusive areas of Vienna. Furthermore, the protect is also support a fish ladder as well[29].

The location of the Island is in between the Danube River and the new Danube (the new water channel; Entlastungsgerinne) with a length of 21.1 kilometer and width of 250 meter.

Technical Description:

The Freudenau power plant (LaufkraftwerkWien-Freudenau) was built by the "wet" construction method from 1992 to 1998 into the riverbed. The plant is located in the middle of the river, between the water gate and the hydraulic power station. In the plant the six largest Kaplan bulb turbines of Europe are installed with a runner diameter of 7.5 meter.

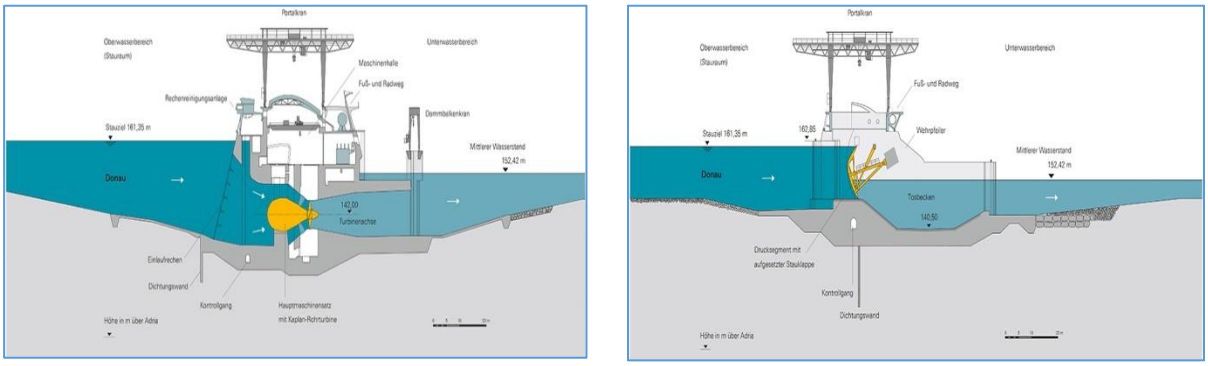


Figure 4.25 VERBUND Hydro Power GmbH (2015)

Each of them drives a directly coupled three-phase generator. Since 2011, the central control station Vienna-Freudenau controls all nine Danube power plants except of Jochenstein. Each year it generates around 1,052 GWh of electricity.

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[29]. A fish ladder is a structure which supports migrating fish passage over the obstacle on a river.

Figure 4.26 An aerial view of the Danube riverbed and the Danube Island (Vienna government, 2015)

4.5.2 Multi-benefits on Environmental, Social and Economic Aspects of flood protection

The new Danube River has many additional benefits besides the main function. The area is not only used for flood protection but can also be a recreational area for social activities for the communities of Vienna. The main benefits of the project are listed in the following:

1. Advantage for the city planning due to its support of the design and the planning of a compact city on the right and the left side along the newly created Danube River navigation.

2. The Danube Island, which is located in between the new floodway channel and the main Danube River, is providing the opportunity of having a recreational area for the community and the multi-use as natural tourism destination[30] and for sport activities on the Island.

3. The chance to positively influence the ground water in the area of the old Danube and the Lobau where is a Vienna floodplain located on the northern side of the Danube.

The city of Vienna (Vienna government, 2015) provides the following activities in zoned areas on the Island:

- Sports (swimming, cycling, canoeing)
- Food and restaurants (bars and nightclubs)
- Recreational entertainment and leisure facilities (grilling, walking with dogs)
- Natural protection and ecological systems (variety wetland animals and a huge diversity of plants)

[30] Annually once per year a festival so call ‘Danube Island Festival’ (Donauinselfest) takes place at the recreational area. It is an open-air free music festival in Vienna, Austria. Usually it is in summer time (mid or end of June) and there are a lot of visitor around 3.1 Mio. (In year 2014) every year.

In summer time, as an approximation 150,000 people visit the recreation area of the island per day. Furthermore, many kinds of animals and plants are living there, surrounded by the city where they normally are not able to live. Especially the northern and the southern part of the island is home to a high diversity of plants and animals, for example, gray herons, greenbacks (frog), beavers, deer, hares (rabbits), cormorants, kingfishers etc.

Thus, the New Danube has been providing the potential related to electric hydrology, flood management, ecology protection, and transport management for city of Vienna prosperously.

In summary, these so called “Multi-benefit projects” are designed to benefit many aspects. The project will be quite suitable in Thailand. The main purpose is to provide flood protection while additionally improving the biodiversity, enhancing water and wildlife habitat in and around the river by letting the river and the floodplains function in a more natural way. The valuable project of new Danube has even more benefits for the public green areas for community recreation, protecting agricultural fields, improving the water quality, increasing the groundwater recharge, and providing public recreation opportunities.

4.6 Chapter Summary

Reflecting the European experiences on flood management from the international cooperation on the European river basins it points out that the process is mainly based on the EU policy of water management. The EU flood protection and planning law, the cooperation of the Rhine River and the Elbe River, the flood action plan and the spatial planning activities which trend to be gracefully efficient in a cooperation of European countries. Likewise, there were lessons to be learned from the massive flooding in 2013 in Bavaria which lead to an improvement of the Action Program 2020 to the Action Program 2020 plus. Another example of an excellent combination of construction measures for flood protection and keeping human activities environmentally friendly is the New Danube “Entlastungsgerinne” in Austria, which is nevertheless performance-oriented and extraordinarily successful in its implementation.

These measures with interdisciplinary flood management presently seem to be the principle components for establishing a flood management spanning from the European governing level to the individual citizens.

The implementation of the European cooperation on transnational rivers is one important program for flood risk management in the future for the European Union. Moreover, the experiences of this European collaboration can be adapted for projects in Thailand to improve and develop flood management strategies. Therefore, the following mind sets have to be included:

1. A clear and concise water management policy, which combines all levels from the national to the local level. This will clarify the roles of organisations and their responsibilities for works in flood management. This is one important step that needs to be included in the future for a better cooperation of Thailand with the various organizations throughout the country. One single voice from one organization is better than many orders from many different parties of varying political entities. A much

clearer policy can be made of working obligations and tasks for each organization that will not over-lap so that the response to flood issues will be more effective. However, the effectiveness of top-down and bottom-up approaches on the flood policy will accomplish a successful cooperation and implementation of actions in the flood management over all of Thailand with proper delineation.

2. The use of laws and regulations should be completely covered on flood issues in all facets. The Water Act and the Building Act are the most effective sections for each European member for the river basin cooperation, whilst Thailand is still limited in using potential laws and regulations on the flood risk management and the land use control. Some flood action plans and land activities are still having a gap in the provision of agreements. Thus, by having efficient laws for flood management processes which includes spatial planning and land use policies thereby minimizes issues by a possible devastating flood in Thailand in the future.

3. The flood risk management and the spatial planning should be appropriately integrated in the cooperation of working groups. Spatial maps and flood risk mapping based on a standard geo-referencing framework maps are necessary for organizations to cooperate successfully. The standardized base maps will be useful for local authorities for identifying flood zones. Flood risk maps and preparing the land use planning in flood hazard areas should also be laid out appropriately. Those measures will support the local government on working more efficiently on flood management in the short term (emergency plans) and in the long term for sustainable flood management in the future.

In the specific case of the New Danube, the flood prevention with a flood channel has been highly effective in solving the flood problems with structural methods while also creating many possible activities along the river. Open space areas provided by the Danube Island have been a great success. Thailand can adapt this flood prevention method and will gain a lot of benefits for the natural, ecological systems, and recreation areas. However, the water retention has to take the proliferation of poisonous animals from tropical countries into consideration (described in detail in Chapter 6). Another challenge is the redevelopment of natural retention areas which have to be integrated in the current flood management and the spatial planning in flood risk zones.

The flood management should utilize all the necessary areas, apply strategies, improve the work plans and optimize the use of the land in flood risk areas by transforming them into recreational areas and eco-tourism areas. As a result, the quality of living in the communities will improve, the natural environment will be enhanced, and public areas can be used for outdoor activities. These strategies and benefits can attract tourists into flood management zones and benefit the reserved-income of local residents.

5 Present situation and prospects

This chapter describes the challenges of flood management in Thailand. The first part provides information based on the Chao Phraya River Basin and the flood plain areas in the Central area of Thailand. The topographic, hydrological characters of the rivers and the majority of the population which is living in the flood plain area are taken into consideration for the representation of the conditions of the flood management.

In the second part, highlights on the national scale of the policy for water and flood management are shown including their strategies, work plans and projects. The research was reviewing working groups of committees who were responsible for the flood management on the national level and on the practical level of the Thai Royal Irrigation department (RID). Many different groups offered many options and projects on flood prevention and adaptation in Thailand.

In the action plan, this research selected three main options from the Royal Irrigation Department and The Highway Department, which were suggesting a flood diversion channel (structural measure of flood management) as a solution for future flood problems.

It is continuing with reviewing the initiative regarding the water management by the King of Thailand (His Majesty King Bhumibol Adulyadej). Those principles suggest many projects in water and flood management that provide the real work practice for Thai people in sustainability fundamentals.

In the last section of this chapter, the research shares a brief summary on the condition of the central flat area of Thailand, human settlement issues and the impact of natural forest resources. From those factors taken into the consideration and from scientific analysis, in the next chapter it is attempted to solve problems on the challenging flood impacts with geodetic approaches.

5.1 Chao Phraya River Basin

5.1.1 The general physical characteristics

Thailand with an area of about 512,000 km^2 and 2,230 km^2 of water can be divided hydrologically into 25 river basins. The main Chao Phraya basin and the other 7 sub basins which are comprised in the Great Chao Phraya Basin are located in the northern and the central of Thailand. (Nakhon Sawan 15°41'52.0"N 100°07'11.4"E and Ayutthaya 14°21'42.6"N 100°34'56.9"E is located 240 km and 70 km from Bangkok respectively)

The average inclination of the Chao Phaya River over its length of 371 km is 5.4 cm/km (1:5). In comparison to the Rhine River in Europe which has an inclination of 27 cm/km (from Basel to the North Sea: 880 km), it can be seen, that the central area of Thailand is completely plane.

Furthermore it shows the flooding problem in the plain area, due to the impossible discharge opportunities in that area (Wunderlich, 2017 March 15th).

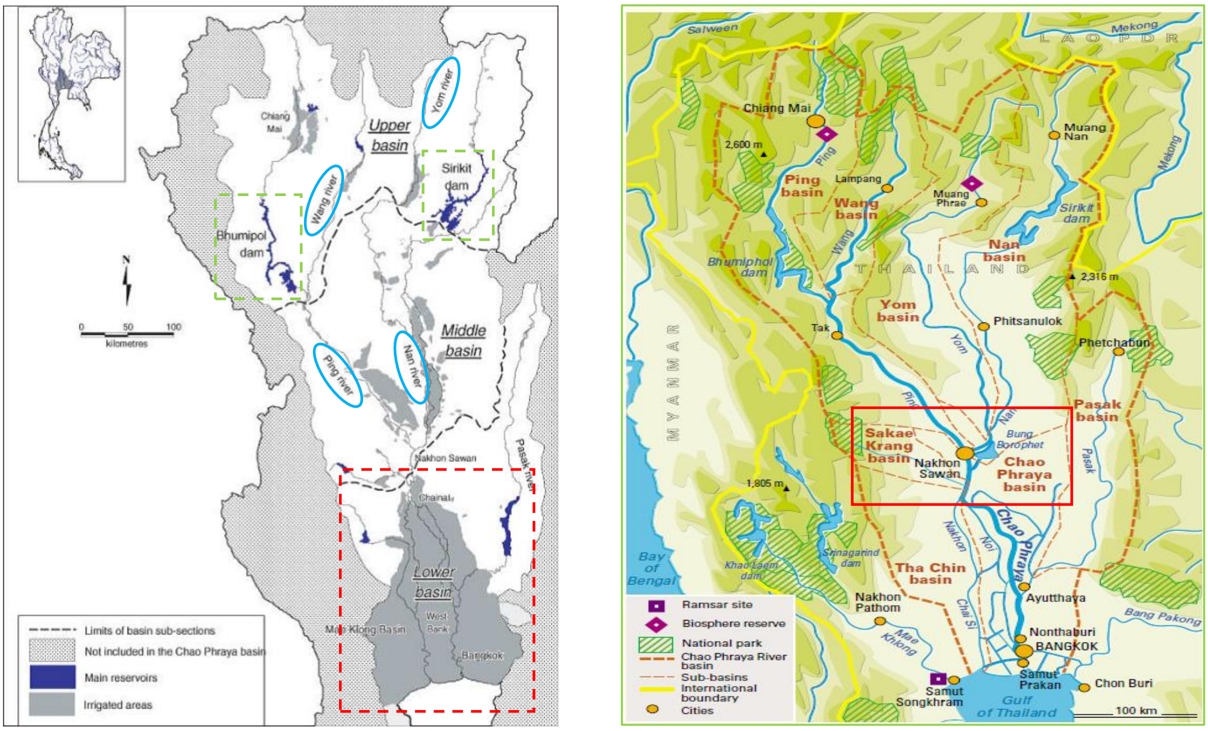


Figure 5.1 Chao Phraya River Basin

(Left) The Chao Phraya River Basin with Irrigation Areas (Molle, 2007)

(Right) Prepared for the World Water Assessment Programme (UNESCO-WWAP, 2003)

The main Chao Phraya river basin supplies the major central region. The Bhomiphol and Sirikit reservoir are located in Northern Thailand. The Chao Phraya River drains from the north to the south. The catchment area covers approximately 160,000 km^2, this is representing about 30 % of the total area of the country and provides dwelling places for 23 million people (UNESCO-WWAP, 2003).

5.1.2 The hydrological characteristics and Geomorphology

The Chao Phraya Basin is divided into two parts at the Nakorn Sawan province:

- The Upper Chao Phraya contains alternating mountainous and low land area along the river. It comprises 4 main sub basins named: Ping River, Wang River, Yom River and Nan River (Figure 5.1 left). The Upper Chao Phraya catchment covers the area of 102,635 km^2, representing 65% of the total basin area.
- The Lower Chao Phraya is a flood plain area[31]. Lower Chao Phraya consists of 4 main sub basins: Sakae Krang River, Tha Chin River, Pasak River, and Chao Phraya River. The Lower Basin covers the area of 55,290 km^2 representing 35% of the total basin area.

[31] The research study is focusing on the area of the Lower Chao Phraya Basin – the area with massive flood impacts in 2011.

The Chao Phraya basin (Figure 5.1 right) is surrounded by the other basins between the neighbouring counties, such as the Kok and Mekong basins in the north, the Gulf of Thailand in the south and the Salawin and Mae Klong basins in the west. The eastern part of the basin is next to the Chi and Mun basins.

Table 5.1 Annual average runoff in the sub-basin (UNESCO-WWAP, 2003)

Sub-basin	**Catchment Area (km^2)**	**Total volume (Mm^3)**
Upper Chao Phraya		
• Ping	35,535	9,073
• Wang	11,084	1,624
• Yom	19,516	3,684
• Nan	32,854	11,936
Lower Chao Phraya		
• Main Chao Phraya	21,521	4,435
• Sakae Krang	5,020	1,096
• Pasak	15,647	2,823
• Tha Chin	18,105	2,449
Total	**159,283**	**98.70**

96 km down from Nakhon Sawan province at the junction of Upper Basin Chao Phraya River, Chao Phraya Dam is located. The Dam was built in 1957 and the construction purpose was to control discharge of Chao Phraya River and use the water for Irrigation benefits along the right and left side of the main River.

Monsoons dominate the weather situation during the rainy season lasting from May to October and supplementary rain from occasional westward storm depressions originating in the Pacific. The average annual rainfall all over the country is about 1,700 mm. At the central plain it is even up to 2,000 - 2,700 mm (DWR, 2011).

Temperatures range from 15°C in December to 40°C in April except for high altitude locations. The whole basin can be classified as a tropical rainforest with high biodiversity (Ibid).

Table 5.2 Hydrological characteristics of the Chao Phraya River basin (UNESCO-WWAP, 2003 pp.390)

Surface area of the basin	159,283 km^2
Annual precipitation	1,179 mm/year
Annual discharge	196 m^3/s
Annual potential evapotranspiration	1,538 mm/year

The geomorphology in the central plain area of Thailand can be separated in three classifications:

1. Fans, higher and lower natural levees
2. Back marshes, deltas, higher and lower mud spits
3. Lagoons, tidal flats and former river courses

Together with the development of the river basin of the Chao Phraya River, and the implementation of water management, the flood situation changed:

1. The lower parts of the plain area in the deltas and the area of Bangkok has further decreased, which leads to a higher flood risk in these highly populated areas.
2. The amount of surface areas where water from heavy rainfall cannot infiltrate the ground increased. Hence, the amount of the water stream during flooding increased.
3. Hard-engineered structures block the water from draining in the flood-prone area, which causes further damage.
4. The rapid increase of the population in areas around Bangkok lets flooding affect more people at once.

5.1.3 Flood character in Chao Phraya River basin

The different types of water course, runoff regimes, flow processes and land use all combine with physical geography to various types of flood events (Ashley, 2007). Broadly speaking, flood events affect urban areas from different causes, each of which are discussed in the subsection below.

1. In mountain areas, the effects of heavy, warm spring rains.
2. Regional weather systems that are blocked by high pressure systems and produce widespread heavy rain over large sections of major river catchments
3. Flash floods in hilly and mountainous regions.
4. Short duration, high intensity thunderstorm driven local flooding on small streams entirely within the urban areas.
5. Sewer flooding associated with blocked sewer overflows to larger rivers or surcharging through manhole covers.
6. Ground water flooding can be a result of prolonged heavy rainfall in certain geological conditions.

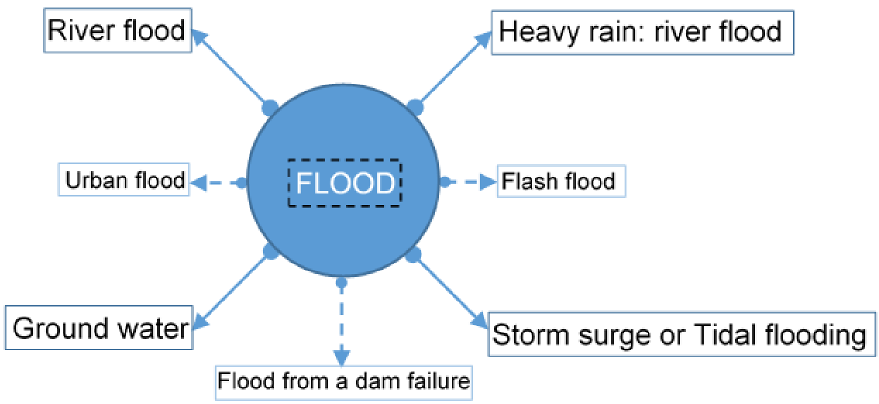


Figure 5.2 Flood condition in the central area of Thailand

The current understanding from this research; in Thailand, central region, mostly the four main types of flood can be found as follows:

- River flood
- Inundation flood from estuary (storm surge or tidal flooding)
- Regional monsoon seasonality (heavy rain)
- Short duration flood or urban sewer overflows and groundwater flooding

5.2 Population density

Due to the increasing population of Thailand since the last decade and reflecting the fact that there is solely a limited amount of land and resources, carefully and wisely planned concepts of controlling the population, the zoning areas, sustainable constructions and the protection of the nature are necessary, especially in the area of this research – flood risk area issues.

This case study area on flood risk management concerns the massive flood area from 2011 for flood prevention and adaptation in the location of the central region of Thailand. Hence, the density of the population in that area has to be considered as one of the criteria for the concept. People who live along the river have to adapt to or be protected from flooding on their own. The local community should create a balance between the safety of the community, the flood protection area and the benefits for the ecological status.

5.2.1 Country population and density

The review of the data of the density of the population in the whole country of Thailand and in the central regions – as defined by National Statistical Offices (NSO) – are necessary to build up a strategy plan and concept for dwelling designs.

Table 5.3 Number and density of population by region in Thailand: 2002-2009

Region	Population (in 1,000 people)		
	2002	2005	2009
Whole Country	62,799.9	62,418.1	63,525.0
Central Region	14,840.1	15,030.6	15,742.5
Bangkok	5,782.2	5,659.0	5,702.6
	Density (in people/km^2)		
Whole Country	122.4	121.6	123.8
Central Region	145.0	146.9	153.8
Bangkok	3,686.0	3,607.4	3,635.2

The population in the central region is defined by National Statistical Offices (NSO, 2015). The data illustrates that the central region of Thailand has a continuously growing population since 2002 (with about 14,840.1 million people in 2002, 15,030.6 million people in 2005 and about 15,742.5 million people in 2009).

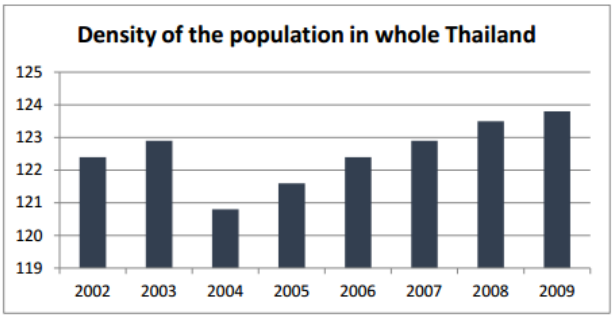


Figure 5.3 Density of the population in Thailand (NSO, 2015)

With the same trend, the density of the population of the central region is steadily rising in the shown years, with 145 persons per square kilometer in the year 2002, 146.9 in 2005 and 153.8 in 2009.The NSO also states, that the Bangkok metropolitan area has the highest number of density in the last decade – in average 3,600 (in detail: 3,642.8) persons/Sq.km. In conclusion, the number and density of the population is increasing, with the only exception in the year 2004 when the Tsunami occurred.

Urban and rural population density of the central region

However, the rate of the population in the central region of Thailand from 2002 to 2009 appears to be steadily increasing. Furthermore, it is important to find out the trends of the urban density and the rural density, because the increasing trend of the population of the whole region is not reflecting the trends of the urban and rural areas.

Table 5.4 Number of the population by region and district boundary: 2003-2009

Regions and Districts	2003	2005	2007	2009
Whole Country	63,079.8	62,418.1	63,038.2	63,525.1
Urban	18,042.1	18,140.1	18,891.9	21,359.7
Rural	45,037.7	44,278.0	44,146.4	42,165.4
Central Area	14,987.0	15,030.6	15,409.6	15,742.5
Urban	4,771.2	4,865.9	5,132.3	5,805.7
Rural	10,215.9	10,164.7	10,277.3	9,936.9

(Unit: Population at the end of the period in 1,000 Persons)

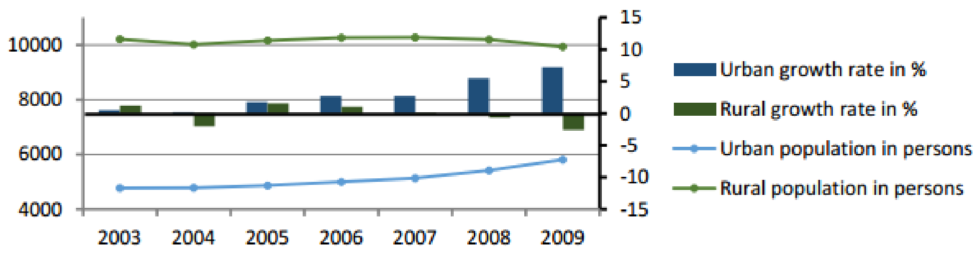


Figure 5.4 The trend & the growth rate of the population of the central region in 2003-2009

By contrast, the data shows that the rate of the population in rural areas is declining even though the rural areas combined have more population than the urban areas combined.

Table 5.5 An example of comparing the population in urban and rural area of the central (NSO, 2015)

Year	Population (in Millions)		Growth rate (in Percent)	
	Urban	Rural	Urban	Rural
2003	4,771.2	10,215.9	0.5	7.2
2009	5,805.7	10,034.5	1.2	-2.6

Based on the data provided, the central region population is growing plentifully in urban areas. Nevertheless, the growth rate jumped up from 0.5 percent to 1.2 percent from the year 2003 to 2009. In contrast, the growth rate of the rural area decreased by 9.8 percent points. Therefore, these data indicate the changing demographics of the central region of Thailand. A possible cause of the decrease in the rural area might be the moving to Bangkok or other central business areas for job opportunities or other personal issues. The management of river flood prevention must carefully consider the density of the population and human settlement.

Population data of the cities on flood management. From Ayutthaya, up to Nakhon Sawan and population data changes in the years 2008 to 2012.

The data of the Table 5.6 demonstrates that the population of the Ayutthaya province has a much higher population in rural areas as in urban areas in comparison to other cities.

From the twenty-two provinces in the central region of Thailand, the Chao Phraya River passes through ten of them. The Chao Phraya River, as already mentioned, forms out of four rivers in the north of Thailand combined to be the main river of the central area. Even though the Chao Phraya flows downwards through almost ten cities, this research only considers seven cities in the area from the Ayutthaya province above until Nakhon Sawan.

The overall total population of each city, urban and rural areas, population density and number of housings are effected from the changing of climate and trend of population growth. In the same time, flooding situations will be more challenging in the future. Therefore, to reduce and minimize those flooding impacts, we need to have major measures to deal with this situation.

Table 5.6 Seven provinces located along the Chao Phraya River (NSO, 2015)

Year	2008	2009	2010	2011	2012
Ayutthaya: Area 2,556.6 Sq./Km					
Total population	769,126	775,157	782,096	787,653	793,509
Urban area	306,149	306,850	309,288	310,538	312,179
Rural area	462,977	468,307	472,808	477,115	481,330
Population Density	300.8	303.2	305.9	308.1	310.4
Number of housing	250,256	258,129	266,483	274,707	283,567
Angthong: Area 968.4 Sq./Km					
Total population	284,831	284,807	284,970	284,061	283,882
Urban area	78,355	78,353	78,111	77,849	77,201
Rural area	206,476	206,454	206,859	206,212	206,681
Population Density	294.1	294.1	294.3	293.3	293.2
Number of housing	84,397	85,838	87,503	89,282	90,876
Singburi: Area 822.5 Sq./Km					
Total population	215,551	215,299	214,661	213,587	213,216
Urban area	58,130	57,850	57,398	56,797	56,517
Rural area	157,421	157,449	157,263	156,790	156,699
Population Density	262.1	261.8	261.0	259.7	259.2
Number of housing	66,744	67,911	69,040	70,306	71,590
Lopburi: Area 6,528.7 Sq./Km					
Total population	753,801	754,452	755,854	756,127	758,059
Urban area	196,706	196,675	197,639	198,290	197,687
Rural area	557,095	557,777	558,215	557,837	560,372
Population Density	121.6	121.7	121.9	122.0	122.3
Number of housing	247,918	252,488	257,115	262,446	267,673
Chainat: Area 2,469.7 Sq./Km					
Total population	335,952	335,420	334,934	333,256	333,172
Urban area	61,086	102,065	101,931	101,070	100,691
Rural area	274,866	233,355	233,003	232,186	232,481
Population Density	136.0	135.8	135.6	134.9	134.9
Number of housing	106,295	108,138	110,438	112,618	115,328
Uthai Thani: Area 6,730.2 Sq./Km					
Total population	327,586	327,871	327,959	328,034	328,950
Urban area	58,296	60,161	59,833	59,444	59,082
Rural area	269,290	267,710	268,126	268,590	269,868
Population Density	48.7	48.7	48.7	48.7	48.9
Number of housing	102,099	104,066	106,260	108,485	110,882
Nakhon-Sawan: Area 9,597.7 Sq./Km					
Total population	1,074,239	1,072,868	1,073,495	1,071,686	1,073,347
Municipality	214,223	211,495	209,766	206,736	205,406
Rural area	860,016	861,373	863,729	864,950	867,941
Population Density	111.9	111.8	111.9	111.7	111.8
Number of housing	350,468	356,627	362,499	368,737	376,391

5.2.2 Land Use in specific cities on flood management

Land use information is mainly divided into urban areas (built-up areas) and rural areas (such as agriculture, forest, water resource and others). The growth of the population in the Ayutthaya province has increased in the same amount in urban areas as well as in rural areas.

The effect of floods on different areas is not always depending on population growth. Although a flood impacts the Ayutthaya province, in urban and rural areas preferential living space will affected. In this flood case, Ayutthaya and Nakhon-Sawan have the most impacts from floods, especially because of the large number of housings located in those areas.

The Lopburi province is not involved in the present Chao Phraya River line. However, the reason to bring the Lopburi city up for consideration in urban and rural population is, that the concept of the new artificial Chao Phraya River is concerning the Lopburi cities as one suitable location for the new river line.

Table 5.7 Land use activity of the cities along the Chao Phraya River in 2008 and 2009 (LDD, 2015)

Land use	**Ayutthaya**	**Angthong**	**Singburi**	**Lopburi**	**Chainat**	**Uthai-Thani**	**Nakhon-Sawan**
Community and Build-up area	216.66 (8.47)	150.70 (15.56)	133.82 (16.27)	378.51 (6.11)	220.47 (8.93)	154.74 (2.3)	548.13 (5.71)
Agriculture	2182.63 (85.37)	753.34 (77.79)	637.54 (77.51)	4392.39 (70.85)	2028.15 (82.12)	2800.23 (41.61)	7475.80 (77.89)
Forest	0.00 (0)	0.00 (0)	0.00 (0)	1124.57 (18.14)	118.83 (4.81)	3586.21 (53.28)	982.78 (10.24)
Water resource	89.28 (3.49)	46.09 (4.76)	48.65 (5.92)	199.13 (3.21)	96.05 (3.89)	83.02 (1.23)	208.88 (2.18)
Others	68.07 (2.66)	18.24 (1.88)	2.47 (0.3)	105.15 (1.7)	5.24 (0.21)	106.04 (1.58)	382.10 (3.98)
Total	2556.64 (100)	968.37 (100)	822.48 (100)	6199.75 (100)	2469.75 (100)	6730.25 (100)	9597.68 (100)

The data of the Table 5.7, which illustrate the information on the land use activities, is from different years: (2008: Angthong, Singburi, Lopburi, Chainat) and (2009: Ayutthaya, Uthai Thani, Nakhon Sawan)

Table 5.8 Land use activity of the cities along the Chao Phraya River in 2000, 2001 and 2002 (LDD, 2015)

Land use	Ayutthaya	Angthong	Singburi	Lopburi	Chainat	Uthai-Thani	Nakhon-Sawan
Community and Build-up area	377.98 (14.78)	72.79 (7.52)	82.24 (10)	399.49 (6.44)	141.63 (5.73)	92.16 (1.37)	544.89 (5.68)
Agriculture	2021.87 (79.08)	859.56 (88.76)	724.22 (88.05)	4767.34 (76.9)	2095.14 (84.83)	3134.80 (46.58)	7782.67 (81.09)
Forest	0.00 (0)	0.00 (0)	0.00 (0)	821.54 (13.25)	148.08 (6)	3440.91 (51.13)	952.24 (9.92)
Water resource	130.56 (5.11)	23.85 (2.46)	15.02 (1.83)	170.71 (2.75)	61.28 (2.48)	21.17 (0.31)	128.95 (1.34)
Others (Mix-use)	26.23 (1.03)	12.17 (1.26)	1.00 (0.12)	40.69 (0.66)	23.61 (0.96)	41.21 (0.61)	188.93 (1.97)
Total	2556.64 (100)	968.37 (100)	822.48 (100)	6199.75 (100)	2469.75 (100)	6730.25 (100)	9597.68 (100)

The data in this table is from different years: Uthai Thani (2000), Ayutthaya, Angthong, Singburi, Lopburi, Chainat (2001) and Nakhon Sawan Year (2002).

It can be seen that there are no forest areas in Ayutthaya, Angthong and Singburi anymore. However, Lopburi, Chai Nat, Uthai Thani, Nakhon Sawan, being four provinces in the upper central region, still have a high density of forests, although some of them have been decreasing from 2000 to 2009.

5.3 The influence of flood risk condition

One of the challenging parts of flood risk management is the consideration of the population in the planning of flood prevention projects. A balance of the benefits for humans and of less impact for the environment has to be created.

In the central area, the growth rate of the population in the urban area and the reduction of the rural population are different. The efficient planning and consideration of the expanding urban areas will be the most important factor to arrange suitable residential areas for former and new settlements along the new artificial Chao Phraya River in the central area of Thailand. More expensive real estates, greater road congestions and more localized air pollution are distinct characteristic of urban images.

Both topographic terrain data and population data are essential for the consideration of flood prevention projects along the Chao Phraya River. With that data in hand, this research suggests avoiding the major river designing pass through the town areas where the majority of the population is living in high density. This reason will reduce relocation of people and economizes the budget for compensation. Furthermore, this research suggests to retain or return compensate conservative forests, preservative ecosystem area and good-soil for agriculture, and therefore not destroying green areas in flood risk zones.

The river projects suggest the development of housing and facilities when it is necessary. The planning and designing along the new artificial Chao Phraya river will begin from non-urban usage concepts along the river track and include water-body and open spaces of the central region as well as recreation and agricultural areas.

The next step of the concept determines the urban usage and the location of residential settlements. The industrial estates will be considered from case to case. The regulation will follow the country plans on regional planning and the land use planning of the city by the Department of Public works and Town & Country Planning in Thailand (DPT).

5.4 The Experiences of relocation in Thailand

Massive relocation projects in Thailand have occurred since Thailand was faced with the tremendous Tsunami disaster in 2004. The result of a powerful Tsunami attacked 12 countries bordering the Indian Ocean. The tsunami left over 250,000 dead and 2.3 million people homeless (Fernando, 2010). In Thailand, many people have lost access to common property and life, and one of the challenge tasks after Tsunami is relocation, moving local people to other safe place.

In term of social aspects, the local authority has rare experience in responding relocated people. For example, psychological aspects like the concept of the sense of places needs to be understood. At present, there are still many unsolved problems as follows:

- Psychology requirement is a basic need when people confronted with big shocking events seem losing their family members and property. It should have strategies on short-term considerations, such as coping with shocks and risk management (Sherwin, 2007)

- Psychology treatment is essential in a process of moving people from their familiar area to a new place, during which time they are still in sadness because of the catastrophe memory of Tsunami disaster. In particular, new settlement is not similar as old community location, which causes those victims feel depressed of their current living situation and more missing home. Therefore, to have some officers come and consult the victims' requirements will be one of the solutions to help those people recover from the disaster before starting to continue normal life. The people would be able to grow positively from this very negative experience (Fernando, 2010).

- Career and income is also a most important issue of basic survives of these local people. For instance, they are deeply concerned about strengthening household income and longer-term anticipation for the future of their children (Sherwin, 2007). Most of local people were earning money from fishery when the relocation project of moving to a new place far from the sea took place. The government tries to create job opportunities but these jobs are still not suitable for their own career as fishermen. The fishermen learned from their ancestor how to make living on fishery and became professional on their career. They inherited those living skill generation by generation, however, those skills are not applicable to new settlement. The victims are used to living in the "sea" lifestyle. They were long-time settled near the sea, so when they move to places like the mountains, they would encounter much problems in working and living. For more example, Morgan woman tribe usually produce fish- net and bring that net for man to use for fishing, whereas, when they move to mountain area, it is hard for them to live in mountaineer way.

- Accommodation and Infrastructure are one of basic requirements. The government and other organizations who tried to support the local people by donation or compensation, were constructing houses that are not fit for those Tsunami victims to live. However, relocation projects or return-home projects have built new villages for those local disastrous victims. People feel uncomfortable with the new home because they used to live in fishermen villages but the new houses are designed in European style (one size fit all) and not unique. Moreover, the cost of design and construction seem to be limited by budget. The new houses seem incomplete for living, especially in summer time the unqualified building material makes them hotter inside as usual.

Therefore, they need to buy more material to re-structure and complete building. Wood from mangrove will be helpful because they can use the wood to construct the houses like in the past, but nowadays it is not allowed by the Forest Act to cut and use these trees. This makes it difficult to live in traditional fisherman houses, mentioned by an old fisherman (Jiramontri, 2014).

Thus, it is good to support the local community during their recovery and disaster management for local sufferers. The authority or the organization that is in charge of housing and resettlement programme should understand local life style, needs to acknowledge indigenous people and basic need of residences; then they can apply culturally appropriate planning solutions (Scheper, 2006).

From my point of view, to relocate local people has to balance the willingness of residences and advantages of relocation management. Local people's participation is necessary in the relocation process, Those ways will help to satisfy both supporters and receivers, and create more efficient cooperation and development of community members life quality on solving problem of disaster management in Thailand.

5.5 Thais situation of water management project

Since 1989, in the beginning of the cooperation of the integrated water resource management, Thailand had six boards for responding on the policy planning and coordination of water resources at a national level.

5.5.1 National Scale

The national boards and committees are consisting of the National Economic and Social Development Board (NESDB), the National Environment Board (NEB) and the National Water Resource Committee (NWRC). The principal is responsible for developing policies concerning the water resource development, management and conservation.

The Food and Agriculture Organization of the United Nations and United Nations Economic and Social Commission for Asia and the Pacific (FAO-ESCAP, 2000) reported that, since 1997, Thailand has been creating a water management committee on Chao Phraya river basin. The flood management issue is one of the six strategies, which were provided by the World Bank and the technical supporting from NESDB who supervised the working group and organizations of the water cooperation. Concerning the Chao Phraya River Basin, six strategies were recommended:

Table 5.9 Strategies on water cooperation in Thailand

No.	Strategies on water cooperation
1.	Establishing the Chao Phraya River Basin Organization
2.	Water supply management
3.	Demand management
4.	Water quality management
5.	Flood management
6.	Improvement of the legal aspect

Thailand Development Research Institute (TDRI, 2013 p.3) reported that "*The management of water resources and flood in Thailand is highly fragmented in the absence of a law governing water resources management"* the cooperation still has some (ac hoc and transitory) confusion, duplication and lack of clarification on the integration of the development and operation of national resource policies and strategies. Those reasons lead to indecision in implementing the water policies.

Hence, the office of the National Economic and Social Development Board (NESDB), which presented rationales in solving flood problems in Thailand, demands to commission about who is responsible for water and floods management in the immediate phase, the short term and the long term. Presently, the working process on in the flooding in 2011 lack of presently discrete group work, the flood management seems to be inefficient.

Furthermore, the National Economic and Social Development Board NESDB (2013) presented in the United Nations Conference Centre the rationales in solving flood problems and mentioned that the government's framework should cope with the aftermath of flood and preventing future floods:

Table 5.10 The sequence of solving flood problem of Thailand (NESDB, 2013)

Immediate Phase	Short Term Phase	Long term phase
• Relieve ongoing floods • Assist flood victims to regain their livelihoods • Repair damaged infrastructure	• Recover economic stability and confidence of population and investors • Prevent losses and damage from possible floods in 2012	• Reform flood management systems to enhance unity and integration • Improve capacity of flood control and warning systems

The suggestion for the long-term flood recovery and prevention plan created by NESDB:

It is important to have the water and flood commission, because this section can help the linking works in between the national policy and local practice.

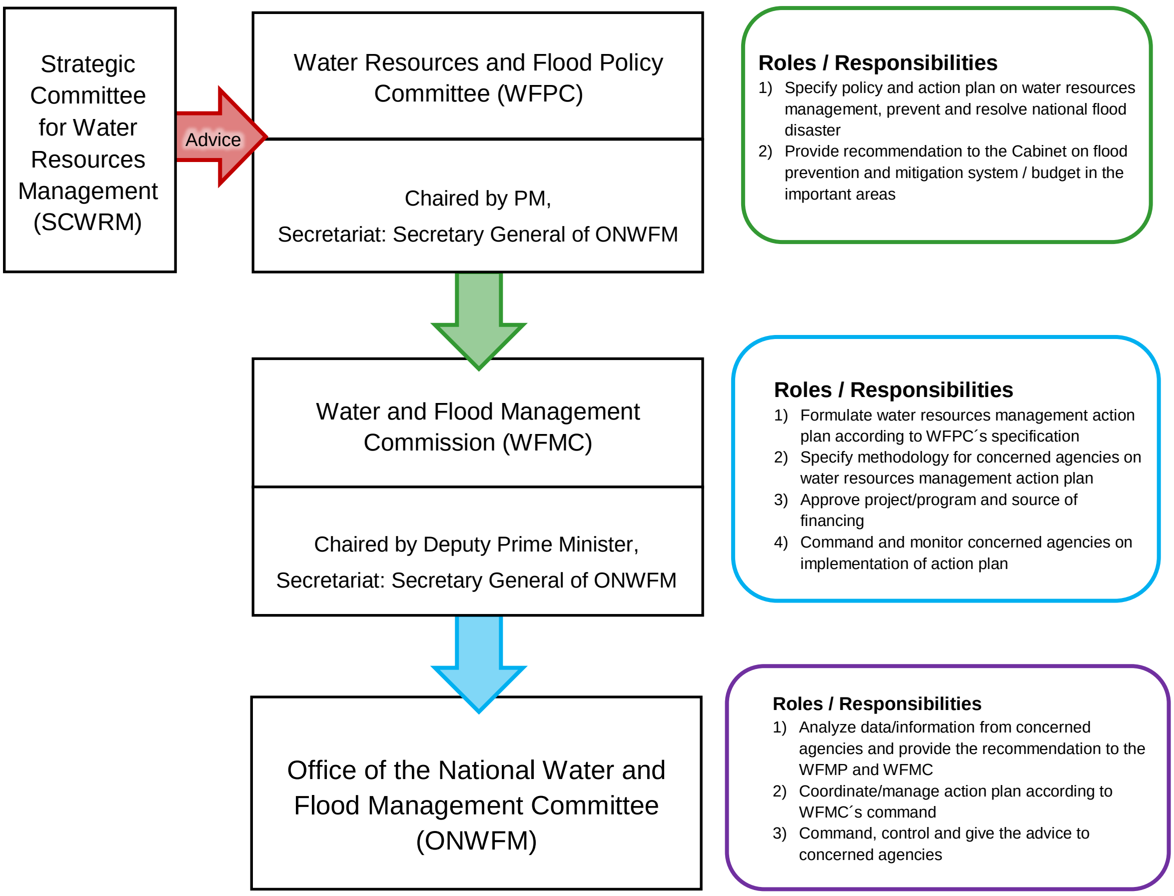


Figure 5.5 Single Command Authority for Water Management (NESDB, 2013)

(A) The strategic Committee for Water Resource Management (SCWRM)

The Strategic Committee for Water Resource Management (SCWRM) formulated the Master Plan on Sustainable Water Resource Management composed of both an emergency and a long-term plan to approve the continuity of solving problems on flooding and water management.

Long-term Flood Recovery and Prevention Plan

<table>
<tr><th></th><th>Strategic Committee for Reconstruction and Future Development (SCRFD)</th><th>Strategic Committee for Water Resources Management (SCWRM)</th></tr>
<tr><td>5 Strategies for Reconstruction and Future Development</td><td>1. Water Resource Management

2. Restructuring of the production & service sectors
• Less exposed to natural disasters and crisis
• Enhance competitiveness to higher value added stage

3. Development strategy for new economic areas
• Distribution of economic development (country and regional)
• Develop economic corridor at sub-regional level
• Create a development cluster with neighboring countries and South-East Asian Region
• Develop border economic zones and border towns
• Enhance connectivity with neighboring countries

4. Infrastructure development (2012 – 2020)
• Enhance current transport network (land, air, marine)
• Enhance country energy security
• Telecommunication infrastructure
• Upgrade current basic utilities to improve quality of life
• Preparation for World Expo 2020

5. Insurance system development
• Create confidence in and awareness about insurance system
• Ensure standards and protection for insurers in all sectors
• Reform rules and regulation of insurance system
• Set up an Natural Disasters Insurance Fund</td><td>Master Plan
for Water Resource Management

1. Restoration and conservation of forest and ecosystem
2. Management of major water reservoirs and formulation of water management
3. Restoration and efficiency improvement of current and planned physical structures
4. Information warehouse and forecasting & disaster warning system
5. Response measures for specific areas
6. Selecting water retarding areas and recovery measures
7. Improving water management institutions
8. Create understanding, acceptance and participation for large scale flood management from all stakeholders

Water and Flood Management Commission (WFMC)

9 Modules on Flood and Water Management Scheme</td></tr>
</table>

Figure 5.6 An example for long-term flood recovery and prevention plan by the National plan (NESDB, 2013)

The SCWRM (2011) developed a master plan, recommending the establishment of three organizations as follow:

(1) The National Water Resources and Flood Policy Committee (NWRFPC) responsible for the formulating flood management policy and propose budget allocation for the cause;
(2) The Committee for Water Resources and Flood Management responsible for executing the adopted policies and measures.
(3) The Office of National Water Resources and Flood Committee, which is the secretariat body.

However, since December 2011 the master plan formulated by the Strategic Committee for Water Resource Management (SCWRM) is explained in more detail in the data below.

Table 5.11 Summary of Work Plans for Water and Flood Management (SCWRM, 2011)

NO.	Work Plan	
1.	Work Plan for Restoration and Conservation of forest and Ecosystem	1) To restore watershed forests in the river basin
		2) To develop additional water reservoirs according to development potential of the areas
		3) To develop a land usage plan that fits with its socio-geographical conditions
2.	Work Plan for Management of Major Water Reservoirs and Formulation of Water Management	
3.	Work Plan for Restoration and Efficiency Improvement of Current and Planned Physical Structures	1) Construction of flood ways or water channels, roads and dams
		2) Improvement of water dyke, reservoir, water drainage and water gateway
		3) Land use planning with appropriate zoning, including setting up an area protection system
4.	Work Plan for information Warehouse and Forecasting and Disaster Warning System	
5.	Work Plan for Response to Specific Area	
6.	Work Plan for assigning Water Retention Areas and Recovery Measure (Improving/adapting irrigated agricultural area into retention areas of around 2 million rai to enable second cropping in all the irrigated agricultural areas	
7.	Work Plan for improving Water Management Institutions	
8.	Work Plan for Creating Understanding, Acceptance, and Participation in Large Scale Flood Management	

(B) The Water and Flood Management Commission (WFMC)

After SCWRM formulated the Master Sustainable Water Resource Management and work plan

The Water and Flood Management Commission (WFMC, 2012) announced the Submission of Conceptual Plan for the design of infrastructure for Sustainable Water Resources Management and Flood Prevention in July 2012, composed of 8 projects as follow:

Table 5.12 The flood prevention projects of the WFMC (2012)

No.	Project
1.	Aiming at the formation of a balanced ecosystem, conservation and *restoration* of forest and soil condition: Project Area is approximately 10 million rai (1 rai =1,600m^2)
2.	Construction of appropriate and sustainable reservoirs in the Ping, Yom, Nan, Sakae Krang and Pa Sak River Basin.
3.	Development of *land use*/land utilization plans, establishment of national and provincial residential areas and major economic areas in the possible inundation areas.
4.	Development of Phitsunulok Irrigation project (North of Nakorn Sawan) to store excess waters temporally during floods, and the Main Chao Phraya Irrigation Project (north of Ayutthaya) to convert existing irrigated lands to retention/retarding areas (Storage volume : approximately 6 to 10 billion m^3, areas: approximately 2 million rai), and improvement of agriculture and fishery industries to increase the productivity yield.
5.	Improvement of canals and river channel dykes of major rivers (the Ping,Wang,Yom,Nan,Chao Phraya,Sakae Krang,Pa Sak and Tha Chin Rivers)
6.	*Construction of flood ways* and national roads to divert discharge that exceeds the flow capacity of main channel from the Chao Phraya, Pa Sak River with east/west routes of the Chao Phraya River to the gulf of Thailand. The structures include flood way with more than 1,500 m^3/s flow capacity and /or flood diversion channel
7.	Improvement of existing systems including database system, weather forecasting system, disaster forecast/warning system and other water management (flood and drought) system.
8.	Improvement of water management institutions including development of appropriate law and policies on flood control, formulation of a single command authority, and management, monitoring and relief activities.

5.5.2 Flood management project (Catastrophic flood 2011)

In the past, Thailand’s government made the decision in the beginning (action in year 2011) for the nation scale project for the water management program, on a budget of 350,000 million Baht or around 8,533 million Euro (1 Euro = 41.01 bath; currency rate from December 2011).

Nine from ten modules were presented, concluding the national master plan of water management project, which covered the issues of the flood and drought management (TDRI, 2013).

Table 5.13 Ten Module Water Management in Thailand (TDRI, 2013)

Module	Projects	Budget (Million THB)	Group pf Company
A1	Reservoir	50,000	1,2,4
A2	Polder (Land use planning); Zoning	50,000	1,2,3
A3	Water retention area	60,000	1,2,7
A4	Dredging the canals	7,000	1,2,3
A5	Flood way	120,000	1,2,3
A6	Flood Information & Geo-datasets	50,000	1,2,5
B1	Reservoir	12,000	1,2,3
B2	Polder (Land use planning); Zoning	10,000	1,2,6
B3	Dredging the canals	10,000	1,2,3
B4	Flood Information & Geo-datasets	2,000	1,2,7

Briefly, these nine modules are consisting of: A1 = Embankment dam and reservoir, A2 = Polder and land use planning, A3 = Water retention Area, A4 = River improvement, A5 = Flood way, A6 = National Data center (the following should be integrated: National Hydro informatics and Climate) and B1-B3, which are representing the same modules as A1, A2 and A4.

The following groups of companies auctioned on this program:

Group	Company (Auction)
No.1	Korean company by Korea Water Resources Corporation (K-water)
No.2	ITD-Power China Joint Venture (Italian–Thai)
No.3	(Thai-Japanese) Joint Venture
No.4	(Japanese-Japanese) commercial cooperation
No.5	Loxley Public Company Limited
No.6	Summit SUT Joint Venture
No.7	Thailand team

Owning to the A5 module, the flood way project will be promoted and planned for being constructed, which is relevant for the formation of a new artificial river. There are three projects which are concerned with the flood diversion channel:

1. Western side of Chao Phraya River
2. Eastern side of Chao Phraya River
3. Outer Ring Road Diversion

Figure 5.7 Strategic Committee for water resources management (JICA, 2013)

(For topography map see Appendix 2 for more details on Ayutthaya: RTSD)

5.6 The flood prevention projects

According to the flood protection on future projects by the Royal Irrigation Department of Thailand, three master plans of the Thai royal irrigation department and the highway department are potentially relevant for performance.

This section aims to review the preliminary design of three projects:

1) Western Chao Phraya River Flood Diversion Channel Project.
2) Project for Feasibility and Environmental Impact Assessment (EIA) Study for the Water Management in the Western Chao Phraya River Areas.
3) Water Management in the Eastern Chao Phraya River Area Downstream of Chao Phraya Dam. Feasibility Study for Flood Diversion Canals on the Eastern Chao Phraya River
4) Flood diversion Channels along the Outer Right No.3 project

The significance of the information for flood protection provides the possibility of solving flooding in Thailand.

5.6.1 Western Chao Phraya River Flood Diversion Channel Project

Flood way on the western side of the Chao Phraya River (Kanu Woraluk – Tha Muang) (RID, 2013a).

This research reviews the plans of the Royal Irrigation Department (RID), which are slightly different from the national water management plans. The previous government team of water management suggests the different starting point in the Nakhon Sawan province. However, the Thai Royal Irrigation Department sets the starting point of the flood way route in the area of the Kanu Waraluk district in the Kamphaeng Phet Province while ending at the Samut Songkram Province. The distance is approximately 288 km. The design of the flood diversion channel will pass through the following 6 provinces: Kamphaeng Phet, Nakhon Sawan, Uthai Thani, Chainat, Suphan Buri and Kanchana Buri.

The main objective of the project is to relieve flooding in the Chao Phraya River basin from the Nakhon Sawan province to the Gulf of Thailand. Before starting the construction, the Royal Irrigation Department had been considering the construction processes which were presented by three consultancy companies (RID, 2013a p.7-1 and p.7-4).

Furthermore, there are four different alternative estuaries of the western flood diversion, which have to be chosen before considering of the construction as well.

The purpose of the report project is to cover the whole water management of the western part of the Chao Phraya River with the following actions:

1. To suggest collaboration and cooperation by working together on the water management of private sectors and public sectors of the western part of the Chao Phraya River.

2. To have an efficient and sustainable water management in the duration of the rainy season and the dry season which will make it possible to reduce flood problems and lack of fresh water supply. In particularly, by satisfying the basic needs of the local residents to gain their acceptance.

3. To make priorities for the important projects for solving flooding and a lack of fresh water supply during the dry season by systematically well managing the projects.

4. To up-grade the standard of living and the quality of life for the local residents who live near by the water management projects by having a good attitude of solving problems together.

5. To select the high essential projects which are connected to the water management strategy of the royal irrigation to make a good preparation for continuing the working progress.

Benefits of the flood way project on the western Chao Phraya River:

1) Reduction and prevention of flooding along the Chao Phraya River Basin from Nakhon Sawan until the Thai Gulf.

2) Extension of the potential of irrigation water drainage, in order to cultivate during the raining season 557,308 rai (1 Rai = 1600 sq.m) = 891,692.8 sq.m

3) People who live near the flood way (radial 2 km) including area of 42 sub-districts, 4 municipalities and 115 villages will have water to consume for the whole year.

4) A new support of water resources from the Mae klong Yai and Kraseaw royal irrigation project in the raining season.

5) The water diversion will support the Mae klong Yai royal irrigation project and Kraseaw royal irrigation project. A bigger dam will keep a higher amount of water, which will help to push back the salt water from the sea in the drought season.

6) Transportation links between the northern- and western-southern parts of Thailand.

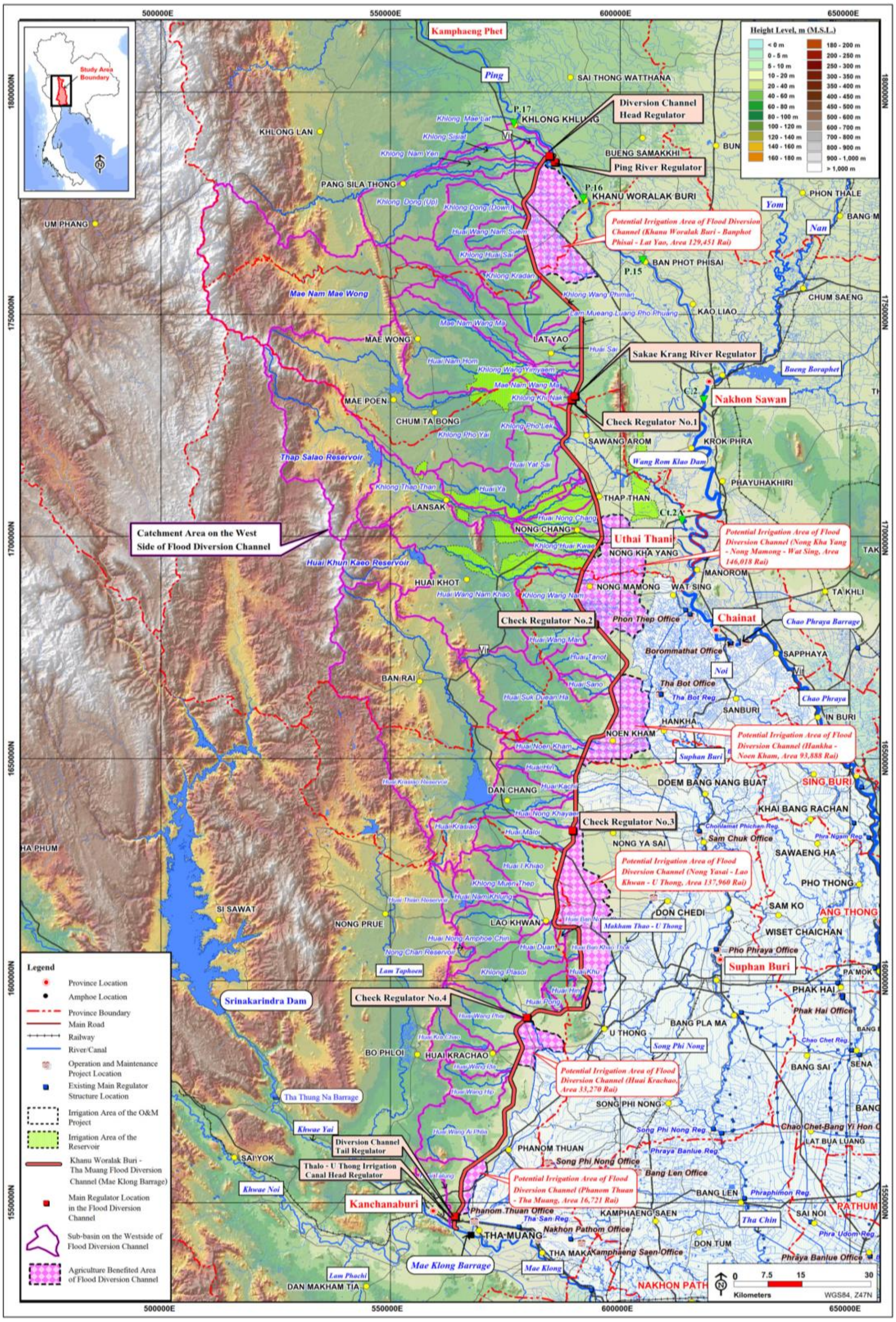


Figure 5.8 Flood diversion channel on the western part of the Chao Phraya River (RID, 2013b)

The western flood way project designed the area ( ) to keep water for agricultural benefits.

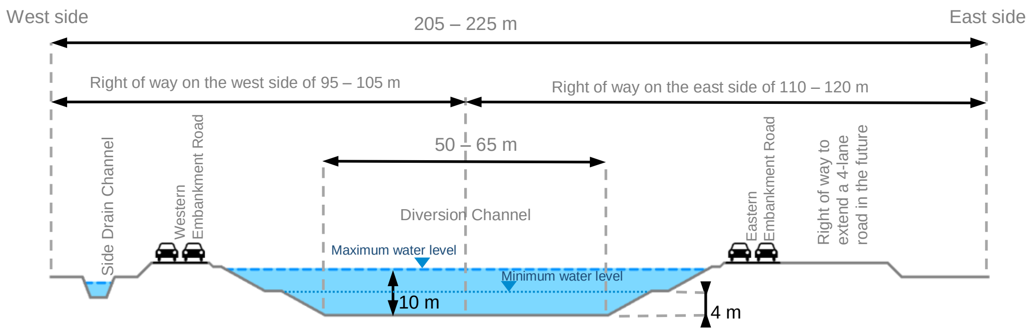


Figure 5.9 The cross section of the Western Chao Phraya River Diversion Channel (RID, 2013b)

The Irrigation Department (RID, 2013b) reported seven issues in the Environmental Impact Assessment (EIA):

1) Impact to the owners of land along the site of the flood diversion channel, which includes 6 Provinces, 19 Districts, 55 Sub-Districts and 39,456 Villages.

2) Impact of the land use on the site of the flood diversion channel which will affect 90% of the agricultural land, 3.9% of communities and 6.1% of forest, water areas and vacant lands.

3) Impacts on forest areas, whereas the EIA emphasized that the impacts are quite small. The project undertakes not to have impacts directly on preservation forests and it will only affect some kind of economic forests or community forests.

4) Impacts on soil digging (for dredging a new flood way cannel), due to the huge amount of soil (approximately 190 million cubic meters). The digging is necessary for the new canal construction. Due to the digging, a huge volume of soil has to be moved to the big vacant land. Some of those soils will be used for building the dyke walls, however, there will still be some soil left over which has to be deposited somewhere. Searching the vacant land for keeping the soil will impact the lands surface in the future.

5) Impact of the sea salt contamination, which will occur when the fresh water from the river will meet with the seawater on the estuary area. This area will affect the ecology systems and the water animals, for instance fish and seashell farms. Especially, in case of long periods of drainage floodwater, the local residents like the fishermen or seashell farmers need the government to pay a compensation payment for them during that period.

6) Impact on the transportation, will be partly beneficial and partly negative. The connection of the logistic systems will support linking the transportation from the part of the north, the west and the south of Thailand. In contrast, there will be a loss of social interaction between neighborhoods that used to travel via small canals between houses.

7) Impact on lands and properties. The local residents who have the right of tenure is approximately 28,358 rai (45.37 km^2) (1 rai = 1,600 m^2). Some of them do not have a title of the land ownership – approximately 8,032 rai (12.85 km^2). Furthermore, around 1,019 multi-functional buildings will lose their own land and properties while the government will pay approximately 3,050 million Baht (76.25 million Euro) in total as compensation. With this project, these local residents will lose their area for working and for earning their income in 6 provinces, 19 districts and 55 sub-districts.

On balance, my conclusion is that those impacts require effective planning and design. The flood way on the western part of the Chao Phraya River seems to have a lot of impacts to local residents according to the Environmental Impact Assessment (EIA), the public interviewing and their participation. Many issues of this project, especially the issues on the communities, cannot be denied, such as the local dwellers complaining that even for a big scale project there is less and not clear information provided for the communities.

Even more important is, that the destruction of the forests or the ecology system will have high impacts and the affected areas will take a long time until they recover. Building back the nature in a short-term period while constructing the project will be not possible. The natural forest is taking a long time to be created in a perfectly natural way.

In contrast, there are more criteria which have to be brought to consideration, for example the topographical aspects of the western part of the Chao Phraya River, which are not so far from the mountain range as compared to the eastern part. As a matter of fact, the western concept of construction can find the water reservoir in the western parts and flow water in the western new diversion channel. However, the highly-elevated area will lead to a more cost intensive construction, while soil textures and also morphology conditions from survey data have to be considered. For the soil data, it is reported that on the western part the soil is mostly mixed with rocks. These circumstances are also proving, that the eastern part of the Chao Phraya River will be more suitable for a flood diversion channel project.

Undoubtedly, the challenge that the planning of the flood diversion channel provides is the search of the proper area with least social and environmental impacts. Therefore, this research is trying to clarify the issues and tries to find the best solution.

5.6.2 Water Management in the Eastern Chao Phraya River Area

Feasibility Study for Flood Diversion Canals on the Eastern Chao Phraya River. Downstream of Chao Phraya Dam

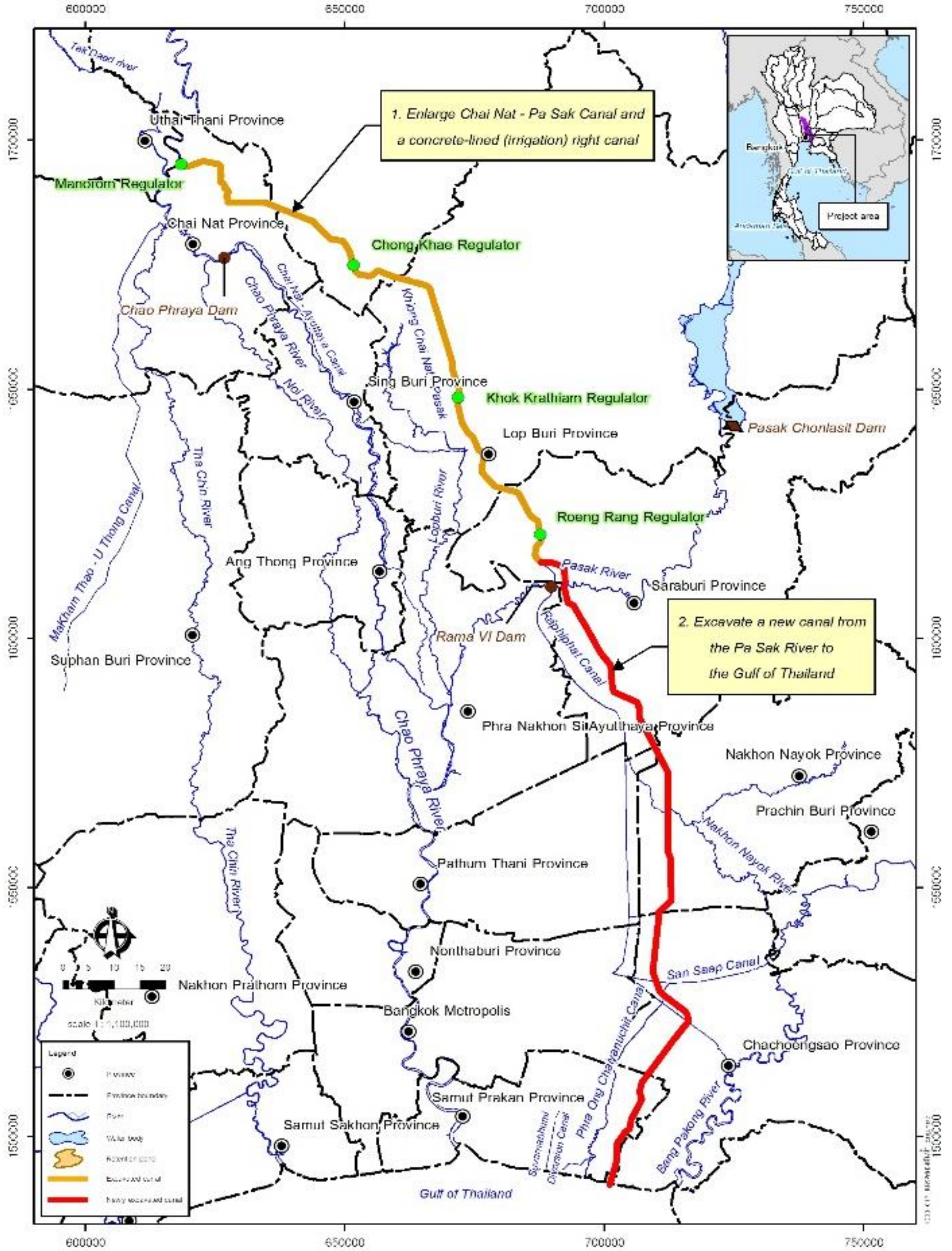


Figure 5.10 Flood Diversion Canals on the Eastern Chao Phraya River (RID, 2013c)

The development of the Flood Diversion Canals on the Eastern Chao Phraya River has a planned length of 268.45 km with a diversion capacity of approximately 1,000 m^3/s.

The project consists of two major components: Section No. 1 is the enlarging and improving of the Chai Nat-Pa Sak Canal (132.85 km) and Section No.2 is the construction of the new Pa Sak-Gulf of Thailand Diversion Canal (135.60 km) partly using (Figure 5.10) stiffened deep cement mixing piles which are resistant to shear. As for the embankment road, soil cement columns are used for supporting road subsidence and stabilizing the canal slope. Other construction elements are the water gates, pumping stations, the new Rama VI Dam and bridges for cars and trains (RID, 2013c) (Figure 5.11-5.13 are modified by Author).

Section No.1 Eastern Chao Phraya Project enlarging/improving the Chai Nat-Pa Sak Canal

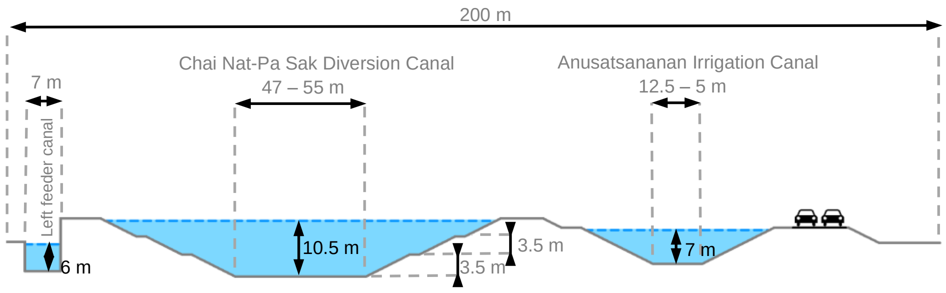


Figure 5.11 Cross-section of Chai Nat-Pa Sak Diversion Canal

Section No.2 Eastern Chao Phraya Project The new Pa Sak-Gulf of Thailand Diversion Canal

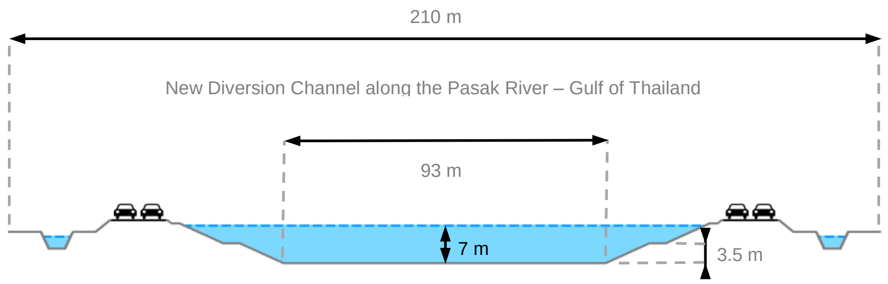


Figure 5.12 Cross-section of the Pa Sak-Gulf of Thailand Diversion Canal from km 0+000 to 23+000

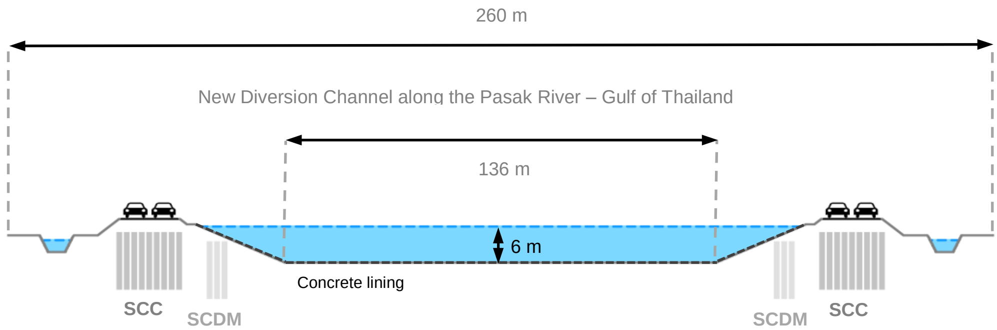


Figure 5.13 Cross-section of the Pa Sak-Gulf of Thailand Diversion Canal from km 23+000 to 134+000

The Royal Irrigation Department estimated the advantages and disadvantages of the project section 1 and section 2. Important selected issues are mentioned in the following:

Section 1: Improvement/enlargement of the Chai Nat-Pa Sak Canal

- Positive aspect:
  The usage of the old canal means less budget investment and the spending of a small amount of land will be expropriated and compensated.

- Negative aspect:
  The high density of encroachments along the old canals, which will create social impacts in terms of relocation of residents.

Section 2: The new Pa Sak-Gulf of Thailand Diversion Canal

- Positive aspects:

  1. The water can be discharged into the sea by only using the gravity, so there is no electricity cost for pumping.
  2. Land prices become higher when the project takes place. New settlements will locate along the diversion canals, which in prospect are supporting the reduction of the population in dense urban areas.
  3. On both sides of the diversion canals, there is a 2-lane road as a new transportation route for people in nearby areas.

- Negative aspects:

  1. High investments for land expropriation and compensation.
  2. Social impacts due to the relocation of people and the possible harms of the confidence of local people to the quality of the construction.
  3. The channel will pass through the wetland area where mangrove and flourish ecosystems could be impacted.
  4. The new canals will separate and change the system of social interaction of communities.
  5. The water transportation of the old canals will be impacted by the new construction.

Even though the project has many benefits besides reducing flood impacts, local residents will suffer from having to relocate from the old dwelling to another new area. Many of them prefer to just accept flooding situations than moving to a new settlement.

In conclusion, the main problems that the RID studied consist of the cost of investment, land expropriation and compensation, social impacts of relocation and environmental impacts. This research agrees to some issues in the project of the Royal Thai Irrigation, however, some problems are remaining which have to be considered in the process of finding the balance solution.

5.6.3 Flood Diversion Channels along the Outer Right No.3 Project

The concept of a flood diversion channel along the outer right of the Chao Phraya River will be constructed with dyke channels parallel to Bangkok's high-way No.3 with a diversion capacity of approximately 500 m^3/s. This project will be the responsibility of the Highway Department of Thailand (DOH).

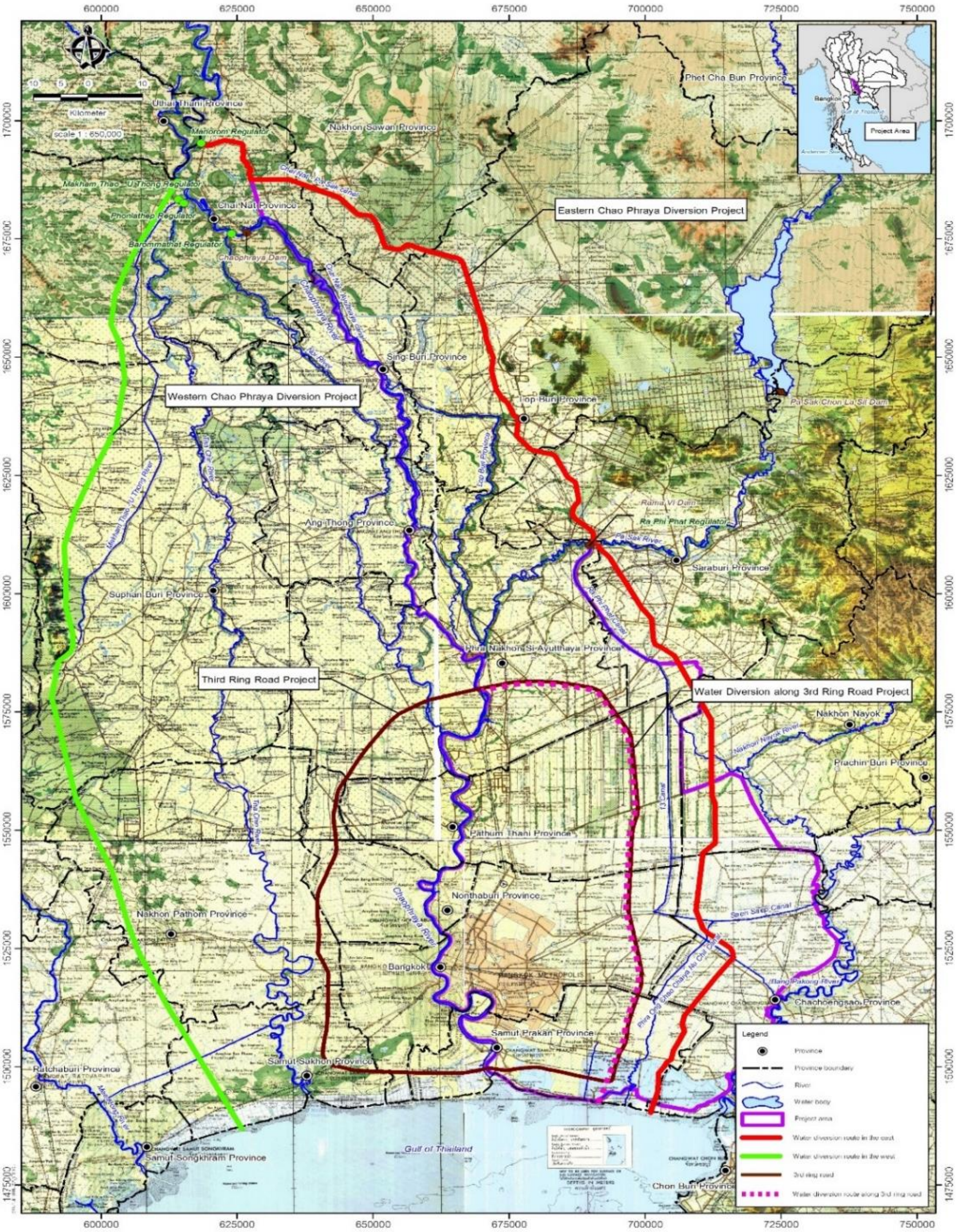


Figure 5.14 The boundary of the Outer Ring No.3 (RID, 2013c)

Flood diversion channel project (▪▪▪▪)

The flood diversion canals along the outer ring road in the east is developed in order to increase the capacity and flexibility of the flood diversion downstream of the eastern Chao Phraya Dam in Chainat, Singburi, Angthong, Ayutthaya, Saraburi, Lopburi, Chachoengsao, Pathumthani, Nonthaburi, Bangkok, and Samutprakan.

The design of the channel will follow along the high way No.3 which belongs to the Highway Department of Thailand and the project´s main purpose is to support flood protection and to provide more benefits in terms of decreasing the traffic congestion in Bangkok. The outer right road (high way) is one of the motorways that links cities. This route is also integrated in various types of transportation systems such as road connection, water and air transportations.

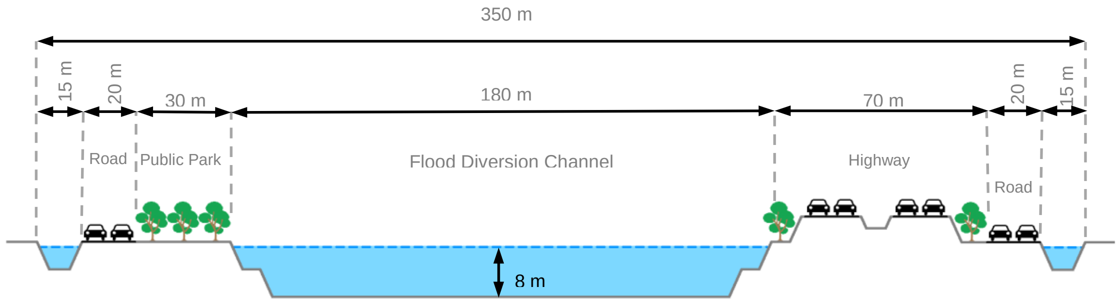


Figure 5.15 Cross section of the flood diversion channel (RID, 2013c) (modified by Author)

The design of the flood way project covers an area along 350 m of the channel with a width of 180 m, the depth of the channel is 8 m. The highway has a width of 70 m while the local road is separated on a 20 m wide road on both sides of the diversion channel. Furthermore, a park area with a width of 30 m is planned. The small diversion channel next to the road will have a width of 15 m on both sides and the length of the whole channel will be roughly 100 km. Ships can use a water gate to navigate to the channel. The character of the outer ring No.3 flood way channel from Ayutthaya to the Gulf of Thailand will be to support other drainage canals on the eastern side of the Chao Phraya River. In this project, the channel is able to contain drainage water of approximately 58 Million cubic meter per day and will reduce the impact of flooding on the eastern part of central Thailand and especially in Bangkok and the out-skirt area. Another benefit of this cannel will be the storage of more than 100 million cubic meter of water during the dry season, where this water can be used for providing a continuous water supply for the expanded community areas in the eastern part. In the same time, that water will be useful for agricultural lands along the new flood diversion channel.

In terms of land development, this project plans to support the developing areas for tourism and recreation and to increase the quality of products of the agro-industry. Moreover, the flood diversion channel on the eastern part of the lower Chao Phraya River, will directly drain the water from the rainfall (that is more than 5,000 km^2 in this area) from Ayutthaya to the gulf of Thailand.

To sum up the present situation, the project of the flood diversion channel will bring a lot of profits in comparison to the other investment of flood protection. This outer ring No. 3 seems to be the project that the government is most likely supporting and providing a budget for in the future.

5.6.4 Local public participation on flood diversion channels

Beyond all doubts, the flood protection projects of the irrigation department for improving or newly constructing the flood drainage system have the agreement of the majority of the local residents of the public participation. Parts of issues tended to be specifically localized problems.

This research summarized the problems of the local public participation in the project area and encountered fourteen issues:

(1) Land encroachment in the area of the irrigation drainage water channels, where many housing are located along the canals.

(2) The soil erosion caused the eastern lower Chao Phraya area to mostly consist of soft soil, which causes high danger during the flooding time.

(3) No collaboration and cooperation between the local authorities that are involved in the drainage water system.

(4) The canals of the water drainage systems are shallow because of lack of improvements to the drainage water system.

(5) Weed problems in many canals are a big threat for the drainage water systems.

(6) Lack of water during the dry season, which leads to scarce water in the canals and not enough water for the consumption of the local habitants.

(7) No regular plan for the drainage time of the water, wrong target group as providing water for consumption in villages not for agriculture, hotel business and industrial sector.

(8) Water gates were damaged and a lack of maintenance occurred which lead to a low quality of water drainage on effectiveness.

(9) The wastewater drained from the industrial areas to the canals makes the water stream flow slower downwards because of blockage of industry waste materials.

(10) Stagnant water in the rainy season while the pipe channels and the bridges display an obstacle for the water drainage.

(11) Smuggle on the water drainage such as opening and closing the gate for personal benefits, for example, fishing.

(12) Lack of local roads along the irrigation canals, which leads to farmers being not able to bring their agriculture product to the market.

(13) Furthermore, the sea tides contain salt water that will mix with the water, making the water supply of the local residents in this area not suitable for consumption.

(14) Sea tides making the road collapse and having more impacts during the flooding season, which can cause accidents for the people who use the roads.

In addition, the report of the Thai royal irrigation department (RID, 2009) has been working on the social issues of the public participation on the project on the eastern part of the lower Chao Phraya River.

The project called “the increasing efficiency improvement of the water management on the integration of concepts with public participation” is particularly improving the understanding of the necessity of the consideration of flood diversion channels.

There are four aims for the efficient improvement of the drainage water channels of the Thai royal irrigation:

(1) To estimate the present situation and the efficiency of the drainage water system of the irrigation project and to bring a solution to improve and develop the irrigation system.

(2) To study the possibility approach for maintaining the buildings of the water drainage system with short-term and long-term projects by including the studies of environment, ecology system, social and economic impacts.

(3) To make a working plan for a short-term and a long-term project with an appropriate investment.

(4) To determine the most efficient approach by preparing for the present and the future situation with the operational manual of the water management while including the modern data bases of the projects.

It should be noted that the improved drainage water areas and the construction of a new flood diversion channel have positive and negative impacts on the local residents who live inside the boundary of the royal irrigation department area and the networks which are connecting internal and external stakeholders

5.7 The appropriate solution for flood protection

This research will illustrate the comparison of the positive and negative aspects of a flood diversion channel on the western and the eastern part of the Chao Phraya River, to find the presently suitable solution for the flood prevention and adaptation measures of a diversion channel.

The survey of the area considers the observations of the current situation, reviews of documents, analysis of alternative solutions and the cost effectiveness and environmental impacts. These criteria support the decision making for a proper new flood diversion channel or a new artificial Chao Phraya river.

Table 5.14 Comparison between the area of the western and the eastern part of the Chao Phraya River (Author)

Evaluation Items	**Western Section**	**Eastern Section**
Physical Consideration		
Topography	Relatively high elevation, due to the geographical character of the western part of Thailand where several mountain ranges, high mountains and steep river valleys are connected with northern Thailand and a long mountainous border between Thailand and Myanmar.	Low-lying land area drained by the Chao Phraya river and other rivers covering the broad alluvial plain. Fertile flood plain and flourished rice cultivation (called the rice bowl of Asia).
Water resource	Major dam of the country in the western area.	Natural self-contained basin.
Social Consideration		
Density of population	The Western region is the smallest populated region (low density) and an area of sparse population. Some areas of the western part still have ethnic mountainous people (Mon–Karen).	The Central area is the most populated region in the country (high density).
Relocation	More impact on the mouth of the river.	More people will get impacted than in the western part.
Economic Consideration		
Financial condition	Less compensation and fewer land expropriation.	High compensation and abundant land expropriation.
Budget of investment	High investment.	Low investment.
Environmental Consideration		
Forest area	High quality of forests and preservation forest which are important natural resources.	Agricultural land and economic forests.
Estuary impact	Flourish organic natural re-sources such as mangroves. Tuna fish areas and seashell shore line farms. Salt farm area and the location of the seafood industry. Extreme erosion situation.	People are taking benefits from living in mangrove forests. Land encroachment. Salt contamination, shrimp farming and high land use changes.

Those characteristics influence the decision of which area will be the most appropriate area for flood protection.

In a probabilistic sense, the considered topography, forests and suitable areas for the new concept design of river on the eastern part of the Chao Phraya River will be the more feasible area, whilst on the western area there will be less problems with the population and the land-tenure. The cost of the investment is on the eastern part lower than on the western part, because of the characteristic of the area which is lower and the gravity will naturally support the flow of the water of the river.

Consequently, this research weights the eastern part as more suitable for the design and the planning of the project of a flood diversion channel or the new artificial Chao Phraya River.

The flat area and the dense population will state a technical challenge that can be solved with geodetic approaches. Therefore, this research will suggest a collaboration on the flood protection plan, modern land management and designs that emphasizes environmental friendly flood mitigation and adaptation approaches in Thailand.

5.8 The initiative regarding water management

From the water management plan (The Chaipattana Foundation, 2015) Thailand has improved the projects for flood management by the King Rama 9 of Thailand (His Majesty King Bhumibol Adulyadej).

The Concept Framework in protection future floods can be divided into three parts:

1. Upper river basin - priority given to slowing down speed of the water flow.
2. Middle river basin - priority given to the water management such as dam management, floodway and monkey cheek construction
3. Lower river basin - Importance given to increasing flows of water out to the sea

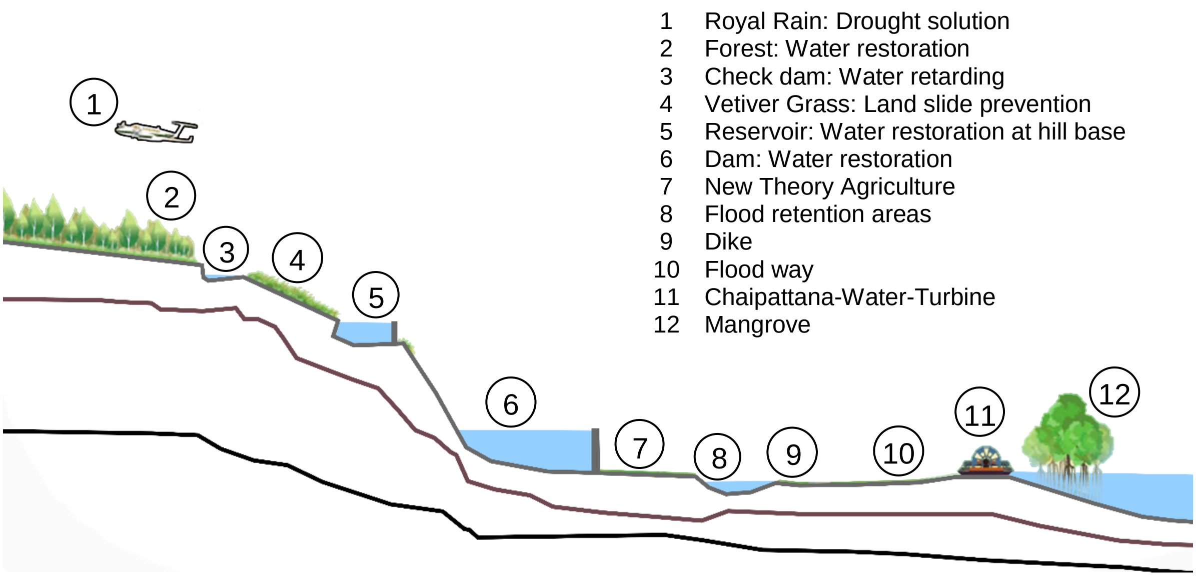


Figure 5.16 King's initiatives regarding water management (NESDB, 2015)

1) Royal rain

The benefits of artificial rain are felt in many sections, especially concerning the support of more water in reservoirs and dams during the dry season not only for producing adequate electricity, but also for local people having enough water for agricultural sectors. Moreover, the dry season leads to impacts from the sea level, which is pushing into the mainland.

This issue will cause a lot of contaminated water with high salinity. Therefore, artificial rain will support more water pushing the salt water back to the sea. Furthermore, the artificial rain will produce enough fresh water to attenuate the contaminated water pollution from the city. In the future, this way may adapt to the floods challenges, when the floods are reduced and the method of using huge amount of fresh water can also clean the city (The Chaipattana Foundation, 2015).

2) Forest / Water restoration

Increasing forestation will bring a lot of benefits to local communities. Especially reforestation above the area of a reservoir where the water retention is located will provide good moisture and sustainable circulation of hydration. In terms of the forest area itself, there will be more nature and activity for forest business and useful section for agriculture, irrigation provided.

For local people advantages is possible that they earn an extra income by providing fuel, living, fruits and trees etc. In case of a natural disaster such as wildfire during the dry season, a rich forest will protect the line of fire serving as a natural barrier and flood protection with the benefit of water conservation for the land. Therefore, this will be an important suggestion to grow forests in the surrounding zone of the new artificial river. This project will bring even more benefits in the case of a flood due to the vegetation reducing the fast flow of the floodwater.

3) Check dam

Check dam is one of the pivotal role of water preservation for utilization. During the rainy season, fresh water can be kept and slowed down before it reaches the downstream area. Mostly, they can be seen in area of the northern of Thailand. A check dam is a way of water retarding which creates moisture in around retention areas (ibid).

4) Vetiver grass / Landslide or Land erosion prevention

Vetiver grass will help slow down the speed of water. In the same time, it will increase the efficiency of depositing sediment along the channels. The vetiver grass enables us to safely plant trees along the riverside and roadsides and to prevent soil erosion and landslide, which can reduce damages to slope mountain, water channel, and agricultural land.

5) Reservoir / Water restoration at hill base

Due to the necessity of keeping forest moisture around the area of the mountains, it is necessary to preserve the upstream area by creating creeks on both side. For the section along the ravine and the drainage channels a small reservoir or weir can be created. A small amount of water can be kept in the reservoirs, while for large quantities of water a reservoir should be created, that drains the water into the area of plantations and crop lands.

6) Dam and water restoration

Uses of dams have multi-purposes such as water supply or the generation of electricity in hydro-electric power stations, irrigation, transportation and especially helping to control and mitigate floods. Small dams, built specifically for the flood protection in the central area of Thailand, store water for the irrigation to provide a supply of rice crops.

7) New Theory of Agriculture

The New Theory of Agriculture is a kind of sustainable agriculture, as it promotes integrated farming, which consists of rice, big trees, small plants and medical herbs. Big trees help improve soil retention and provide natural fertilizer, while small plants help retain moisture. Also, prolific wind-blown seeds from trees on hilltops help accelerate natural regeneration.

This is a kind of farming that helps improve the ecology, conserve the environment, and benefit people's well-being. Several success stories of farmers who employ the New Theory of Agriculture can be witnessed from all over Thailand (RDPB, 2009). These farmers now have better lives and continue to conserve the environment.

8), 9) and 10) The Monkey Cheeks Project

The Monkey Cheeks Project is the concept for flood mitigation with the provision of nonstructural measure. *In particular, this project (Figure 5.17) can apply working with water retention area (No.8), dyke (No.9) and flood way (No.10).* The project is inspired by the way monkeys consume their food, store the food in their own cheeks and take gradual crewing. It seems that this is the best technique for water retention/detention by using natural retention areas or reservoirs to collect fresh water during heavy rainfall and while the sea level does not allow to drain the fresh water.

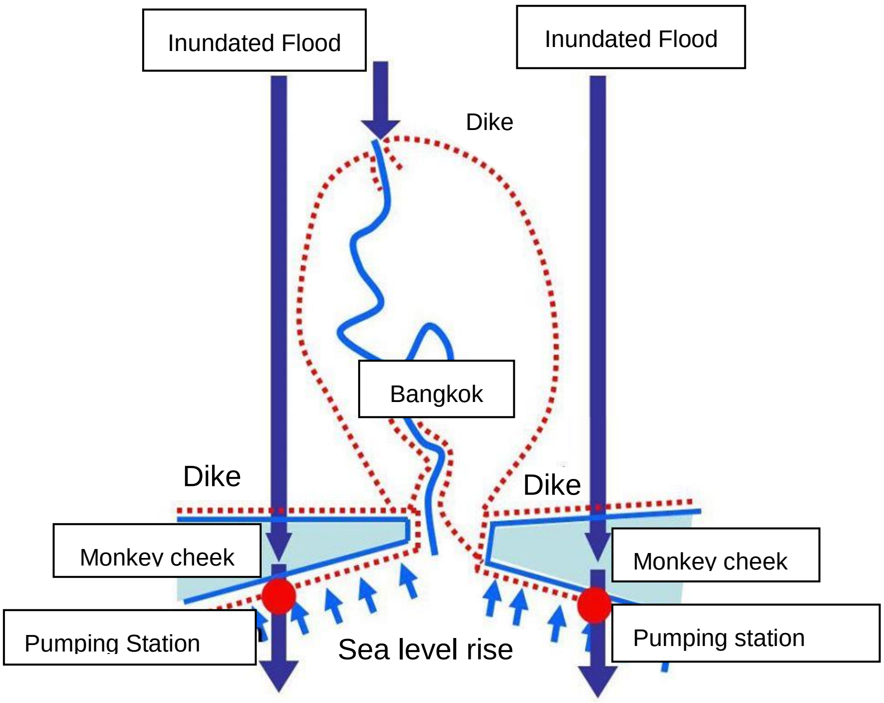


Figure 5.17 The Monkey Cheeks project (RDPB, 2009)

After the heavy rainfalls stopped and a suitable time comes when the sea water level decreases, water that is excessive to be kept in the reservoirs can be naturally drained into the sea using the gravity (Gravity Flow), while keeping an appropriate amount of water in the canals for benefits of the water consumption.

Project Monkey Cheeks (Water retention area/ Green belt); correcting water from heavy rain and floods, when water is over-adequate, to drainage into the sea by using the way of the gravity flows. In prerequisite, the central part of Thailand has one important project that supports the flood management. This project is called “water retention basins” (Monkey Cheeks) and is planned as a long-term solution for flooding. The response of the authority concerns the Bangkok Metropolitan Office, the Royal Irrigation Department and the Local Municipality.

11) “Chaipattana Aerator”

This project is fighting water pollution with the modification of the flotation waterwheel pump to work as an aerator. The implementation has produced a satisfactory result in making the water cleaner, reducing foul odor, and increasing the oxygen content in the water where aquatic animals like turtles, snapping turtles, and fish can inhabit safely (The Chaipattana Foundation, 2015).

The Chaipattana Aerator is widely accepted for the efficient treatment of waste water of both domestic and international communities. It is capable of solving and improving the quality of water through the use of a simple technology, however, with immeasurable benefits and importance to the existence of environmental responsibility (ibid).

12) Mangrove

Mangrove forests aim to improve the water conservation by preserving soil, fertilizer and water quality. Mangroves are located in the wetlands of estuaries where low-lying, sandy and mud-flat areas are seen. Mangrove forest will support the breeding ground, the deterioration of coastal swamps and it will filtrate wastewater pollution. Furthermore, the Mangroves will be included into the ecosystems of the marine inhabitants and fish. In this section, many projects were mentioned that were established by His Majesty the King of Thailand. The projects are regarding the water management, the including of water conservation, water pollution and disastrous floods, droughts and water for irrigation (ibid).

This research will provide more information concerning those projects in the next chapter, in the section of water retention under the Thai conditions and the minor efficient support in flood management with the major scale measure.

5.9 Chapter Summary

Changing Thai politics has had a significant impact on flood protection and adaptation in the central region of Thailand. The National Flood Policy group has set up a committee for working on flood management. The new government modified the plans of the flood management that previously set needed investments in flood preventative measures and replaced with un-clear planning and process issues. The purpose of the modified version of the flood plan is to cooperate with local communities to benefit them while having reducing costs and avoiding impacts on the environment.

The Chao Phraya River encounters various challenges. There are topographically flat areas, a high density of population and forest resources that are to be traversed. The western and eastern parts of the Chao Phraya River have been studied by the Thai Royal Irrigation Department which eastern part of Chao Phraya River offers flood diversion channels to solve flooding problems by re-designing useful irrigation systems. To avoid a conflict with land acquisition and to allay protesting communities this solution was planned within a participation program of local dwellers and all stake holders whom were concerned with the project.

There have been many projects that were researched. Existing irrigation was to be utilized in many of the growing flood prevention projects. Adding an alternative way for a Chao Phraya River on a natural base of construction seems to be the most suitable measure for minimizing flood problems. The main terrain feature analysis supported the conclusion that the eastern part of the Chao Phraya River is a suitable area for just such a creation.

However, the agreeable conditions of the topography contain problems with the high density of population and some environmental areas in the eastern proposed area. Those high density and environment issues will be a focus of challenges. The idea of having a newly designed artificial river will be weighed by the combination of the benefits of reducing the flooding impacts with the reduction of conflicts within the community as much as possible.

The use of the precise Digital Elevation Model (DEM) is an innovative technology that can be used to study the proposed river. With these studies, the calculations of river capacity needs and suggestions on structural and non-structural concepts can be more intimately examined.

This research has found that it will be prudent to create a new alternative to minimize flooding. The proposed river can be used as a flood diversion channel while adding positive environmental aspects, improving the ecological condition of river, and working within the natural resources along the channel. The most important circumstances to consider are the topography, the highly-populated areas, and the environment. Those three key elements will bring significant cognitive challenges in the design and planning. The addition will be a more effective solution by supporting the reduction of flood hazards in the central regional area of Thailand. Coupling the provided geodetic approaches with modern land management will eventually create a flood management on major scale measures for a suitable flood prevention and adaptation in Thailand. The next chapter will provide the details.

6 The need for big scale measures

This chapter concerns various methods to solve flood situations in Thailand along the main river of the central region, the Chao Phraya River. The first vital part will consist of the geodetic development with flood management which will suggest a large-scale addition of a new artificial river. The flow calculation for the suitable topographic solution of a new artificial Chao Phraya River design will utilize an advanced remote sensing data from the German satellite mission TerraSAR-X and Tan-DEM X. The Digital Elevation Model (DEM) data was provided from the DLR (German Aerospace Center) which is currently the most precise terrain elevation instrument with a height accuracy of 2-4 m and DEM post spacing high resolution of 12 m (0.4 arcsec). This up-to date Hydro DEM geo-information is making it possible to achieve the most suitable artificial river design efficiency. The raster flow analysis of the DEM information with ArcGIS will apply for this research. Following, the calculation of the river discharge, water stream velocity, river line inclination and the volume of the new river cross section (soil movement) will be performed. From the results, an alternative river design can be created in the central area of Thailand.

Secondly, the plans for the new river will also be supported by modern land management. The existing factors of human settlements, natural forests, and ecological protections must be brought into consideration during the planning and designing phases. There can be an avoidance of flood risk areas by having proper land use zoning, building regulation, infrastructure service, and land activities will be recommended. To be in harmony with nature, specific activities in the recreation area along the new artificial Chao Phraya River can be presented. The increasing natural protection along with the natural water retention will be positive alternative points in the design of the new artificial Chao Phraya River.

Finally, the cooperation among the organization and effected communities needs to be maintained even after the creation of the new artificial Chao Phraya River. The synergistic relationship and good intention can positively influence the long-term flood prevention and adaptation in Ayutthaya and the central area of Thailand thereby reducing enmity on socio-economic issues. The research summarizes this chapter with the integral knowledge of geodetic approaches of flood risk management.

6.1 Geodetic Approaches

6.1.1 Definition and Classification of Geodesy[32]

According to the classical definition of F. R HELMERT (1880), geodesy (γῆ = earth, δαίω = I divide) is the “Science of the measurement and mapping of the earth’s surface”.

[32] Wolfgang Torge Geodesy 2nd Edition (Hannover, May 1991; p. 1) Publishing by Walter de Gruyter (Torge, 1991)

To this day, this definition has retained its validity; it includes the determination of the earth's external gravity field, as well as the surface of the ocean floor. With this definition, which has to be extended to include temporal variations of the earth and its gravity fields, geodesy may be included in the geosciences, and also in the engineering sciences.

Geodesy can be divided into the areas of global geodesy, national geodetic surveys, and plane surveying (Torge, 1991)

- *Global geodesy* is responsible for the determination of the figure of the earth and of the external gravity field.

- *A geodetic survey* establishes the fundamentals for the determination of the surface and gravity field of a country. This is realized by coordinates and gravity values of a sufficiently substantial number of control points that are arranged in geodetic and gravimetric networks. In this fundamental work, the curvature and gravity field of the earth must be considered.

- *In local surveying* - topographic surveying, cadastral surveying, and engineering surveying; the details of the terrain are obtained. These details are used as a reference surface for horizontal positioning of the ellipsoid and are used in geodetic surveying.

6.1.2 Geodetic development

Wunderlich (2016) provided an overview on geodesy's various range of methods and applications:

- Geodesy is the science of determining the earth's shape and its gravity fields.
- Geodesy involves geometry, mathematics, physics and teaches general methodology.
- Surveying – as a part of geodesy – focuses on practical measurements and their evaluation (data processing) as well as on instruments and sensor technology.

Nowadays, geodesy invention involves in space techniques such Global Navigation Satellite System (GNSS) via laser scanning in multiple approaches down to the very precise engineering and industrial surveying.

For the design and planning of flood prevention and adaptation on this research, geodesy is mostly dealing within geodetic surveying on terrain information.

6.1.3 Geodesy and other disciplines

For the relation in between surveying and geodesy it is important that surveying constitutes the practice of positioning and geodesy is the theoretical foundation of surveying. Considerably in scientific and technical aspects, disciplines of geodetic information, positions or other knowledge are needed. The information of geodesy and other disciplines[33] is essential

[33] Refer to KRAKIWSKY AND VANICEK [1976], (U.S.) COMMITTEE ON GEODESY [1978], MUELLER [1978], HIEBER AND GUYENNE [1978], and RINNER [1979] Cited in PETER VANICEK (1986 p. 20).

which the author intends by clear citing of data from original version and provides the conclusion after the description as following (VANICEK, 1986 p. 20):

a. *Mapping: It is well understood that there is a need for an areal network of appropriately distributed point (geodetic control) of known horizontal and vertical positions for the production of maps ranging from small scale maps of entire countries to large scale maps used by municipalities. The establishment of this control is clearly an important geodetic task.*

b. *Urban management: In the urban environment, the locations of man's creations, such as underground utilities, must be defined and documented for future reference.*

c. *Engineering projects: During the building of large structures, such as dams, bridges, and factories, it is necessary to lay out the various components of these structures in predetermined locations. For this purpose, coordinates of one kind or another are used, so the availability of control points is naturally desirable. As well, it is often necessary to know the movements of the ground and water levels prior to, during and after the construction. In case of dams, water tunnels, irrigation projects and the like, the exact shape of equipotential surfaces of the gravity field should be known.*

d. *Boundary demarcation: the rigorous definition of international and intranational (provincial and state) boundaries is of paramount importance. Emphasis has also recently been placed on the speedy and accurate description oil and gas leases, even in remote and inhospitable parts of the world as the arctic, the North Sea, and various continental shelves. The positioning and staking out of these boundaries is most economically son by relating them to a framework of points with known horizontal coordinates.*

e. *Ecology: It has been realized in the past few decades that it is necessary to study the effects of human actions on the environment. One such effect is the movement of the ground caused by the removal of underground resources (including water, oil, and mineral) or subsurface disposal of waste. The detection and monitoring of these movements is a geodetic problem*

f. *Environmental management: It has been recognized that the establishment of environmental data banks, to serve as integrated information systems for transportation, land use, community and social services, land titles extracts, assessment of tax data, and population statistics, should be based on land parcels whose locations are uniquely defined in terms of coordinates.*

g. *Geography: All the positional information needed in geography is provided by geodesy. Even though the accuracy of positional or other geometrical information used by geographers in generally much lower than that needed in the fields described above, this information is of a global character that only geodesy can satisfy.*

h. *Planetology: It can be argued that this is a part of either astronomy or geophysics. Be that as it may, planetology uses methods for studying the geometry, gravity fields, and deformations of planets that are identical with the extraterrestrial methods used to* *geodesy. Thus, practically all of geodesy is applicable to planetology and geodesy, some geodesists regard the determination of the shape and size of planets and their gravity fields as part of geodesy.*

i. Hydrography: Some consider this field to be a part of oceanography, while others make it a special (marine) branch of surveying; either way, it has a somewhat special relation with geodesy. It may be understood as the practice of positioning at sea, combined with depth sounding.

As mentioned before, the author considers almost all those subjects to apply for flood management in the project. Adding a new summary on this research is relevant as follows:

From my point of view, geodesy is important in theoretical and practical tasks for many useful interdisciplinary characters – surveying foundation, geo-information, position on the earth etc. Those subjects will lead to a useful guide to flood catastrophic observations and the flood management plans.

Table 6.1 Geodesy and other disciplines

Mapping	Technical response utilizes the topographic analysis and flood hazard maps are created in terms of flood planning.
Urban management	This subject is essential because of the flood impacts for high density human settlement areas. The design of river bed will use suitable material in urban area. Urban management is involved in infrastructure and facilities having geodesy support to solve the flooding issues of future settlement areas or public infrastructures (hospitals, schools and service buildings).
Engineering projects	This process is relevant for the creation of a new river construction combined with technical tasks and flood management requiring the boundary cooperation in terms of geodetic tasks. A cooperation across boundaries will allow for clear responsibilities in flood prevention and construction design.
Ecology and environmental management	These factors are supportive methods. Reduction of ecological systems will be obviously presented by monitoring with remote sensing equipment such as forest and wet land management.
Geography and geo-information	These main advances are the most essential tools to describe the position of infrastructure elements on the earth (coordinates, latitude and longitude, Geographic information system (GIS) and The Global Positioning System (GPS), etc.
Planetology	The gravimetry, with its knowledge on the gravity flow of water is one crucial factor for a new artificial river's inclination. The vital knowledge can reduce the cost of investment drastically.
Hydrography	Flooding and other relevant incidents such as tidal effects and rising sea level that submerges land are supported by data from flood analysis. The depth and width of the river will be calculated with the combination of geodetic works and hydrological management

All that information is crucial for flood management; it is necessary to use geodetic technology and geo-data to address the construction of the river, environmental issues and the changing land use patterns. Additionally, soil surveying, geomorphology and geology should be considered as well in the foundation of the geodetic supporting.

6.1.4 Usefulness of Geodesy

Surveying and mapping are major subjects of this research. Surveying has a variety of methods whereas the basic concepts are defined as in the following:

"Surveying may be defined as the science of determining the position, in three dimensions, of natural and man-made feature on or beneath the surface of the Earth". These features may be represented in analogue form as a contoured map, plan or chart or in digital form such as a digital ground model (DGM). (Schofield & Breach, 2007)

The geodetic methods in this research are concerning the flood adaptation projects which are mostly using the surveying for planning, design and construction of works on the surface, especially in the case of a new artificial river line and suitable water retention areas.

The basic three types of earth surface surveying are important tools in this research which are introduced in the following:

1) Terrestrial Surveying is the "common" surveying which is using total station, levels and GNSS[34] receiver. For the flood management research, it may be possible to apply this surveying for measuring such as channels, riverbanks and the water catchment areas. The preciseness and accuracy of geo-data is rather high. However, the working range is limited. This method will use and combine data with other types of surveying. The traditional surveying is suitable in case of district surveying and gaining a specific detailed design for the water area in the community.

2) Aerial Surveying provides aerial photography and Airborne Laser Scanning. Airborne laser scanning is a rapid, high accuracy and efficient method of capturing 3D data of large areas, such as agricultural land or forestry filed, urban areas, industrial plants, etc. Inertial Surveying Systems (ISS) observe position and attitude for the field works. Airborne Radar Profile provides two-dimension information. In the present, aerial photogrammetry can also be performed by Unmanned Aerial Vehicles (UAV). The UAV can survey in dangerous areas, for example in flash flood areas and some difficultly reachable areas where walking surveys are not possible. UAV will provide fast information in those cases, and the data will support quick decision making.

[34] GNSS (Global Navigation Satellite System) is a satellite system that is used to pinpoint the geographic location of a user's receiver anywhere in the world. Two GNSS systems are currently in operation: the United States' Global Positioning System (GPS) and the Russian Federation's Global Orbiting Navigation Satellite System (GLONASS). A third, Europe's Galileo, is slated to reach full operational capacity in 2008. Each of the GNSS systems employs a constellation of orbiting satellites working in conjunction with a network of ground stations (Rousen, 2005).

3) Satellite Geodesy and Remote Sensing are the measures with which this research mostly is dealing with. This data-base is accurate with great flexibility and reasonable accessibility to remote areas. Mostly, wide area satellite based laser surveying is relevant for this research - the two types of satellites that are in use at the moment for scanning the Earth's surface are TanDEM-X and TerraSAR-X. However, Landsat and Spot are the free open source, we will use them to compare geo-information.

- **Section of analysis on using geodetic surveying**

The implementation of the methods will be divided into three levels: Firstly, the Satellite Geodesy on the Digital Elevation Model (DEM) from the DLR will provide rough information about a suitable new artificial river line with a resolution of 12 m. Secondly, an Airborne Laser Scanning will imply for more precise data with higher resolution (suggestion for a future work). Lastly, the highest accuracy and preciseness will be achieved by measuring and walking surveying in smaller areas which are considered suitable for the project from the first two steps.

Nevertheless, with the time limited of this research, the potential to use satellite surveying as first step of the decision making is used and walking surveying as an only observation site as second step must follow.

To sum up on this part, the condition of great area of research study, for the new artificial river where the area is large along the current Chao Phraya River (Covering research area with each phase of the new artificial suggestion around 150 km), the satellite surveying will have suitable tools for the first step of creating the new river line and preparing for suitable areas for natural water retention in urban and rural area.

6.2 Geodetic remote sensing

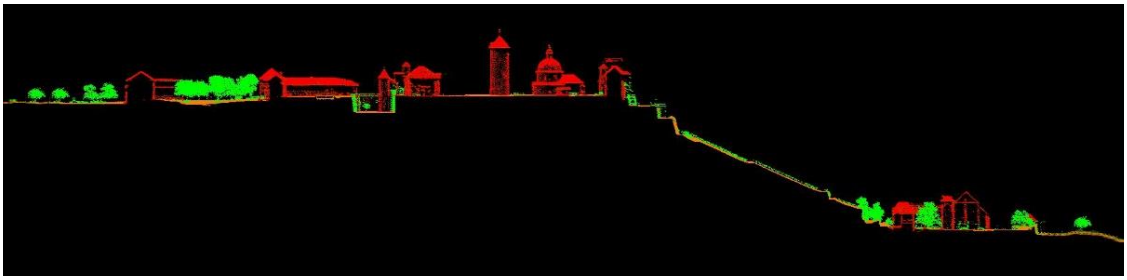
In remote sensing energy emanating from the earth's surface is measured using a sensor mounted on an aircraft or spacecraft platform. The measurement is used to construct an image of the landscape beneath the platform (John et al., 2006).

Remote sensing is suitable for enormous areas (Richards, 2012). The advantage in the first place is to find the approximate course of the new artificial Chao Phraya River. The Digital Elevation Model (DEM) interpretes the earth's surface and provides precise data from a large-scale area. Elevation data is one of the most essential aspects of assessing flood risk and for river designs and planning. It is necessary to use high terrain quality of DEM for calculating the average altitude, slope gravity, aspect, drainage, path simulation, etc. The flood extent and depth should be determined by the elevation information. For the new artificial river design, the first step of consideration should be the terrain surface of the research area.

6.2.1 Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) is a digital model or 3D representation of a terrain's surface. The topographic surface is arranged in a data file as a set of x,y,z coordinates where z equals the elevation. The comparative analysis of differences in ground, height, elevation and terrain are distinguished with two kind of DEM data sets; the Digital Surface model (DSM) and the Digital Terrain model (DTM). DTM represents the natural surface, i.e. the bare earth (Li et al., 2005).

This research uses these models for the new artificial river design and other benefits on topographic mapping, flood prevention, drainage mapping, river planning, ecological and forest preservation and infrastructure construction.



	Digital Surface Model
	Digital Terrain Model
	Vegetation

- **DSM** = Earth Surface including objects on it
- **DTM** = Earth Surface without any objects

Figure 6.1 The difference between DSM and DTM in Festung Marienberg; Würzburg, Bavaria, Germany (LBDV, 2016)

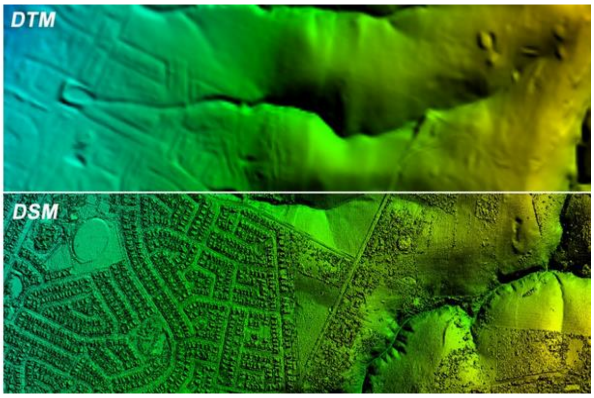


Figure 6.2 Digital Terrain Model vs Digital Surface Model over Adelaide, South Australia (Aerometrex, 2011)

As online data, there are open source and public data sets of Digital Elevation Models (DEM) which are called the Shuttle Radar Topography Mission (SRTM) and the ASTER Global Digital Elevation Model ASTER GDEM:

6.2.2 The general difference between SRTM and ASTER GDEM

1) Data from the Shuttle Radar Topography Mission (SRTM) is DEM data from NASA in 2009. The elevation models derived from the SRTM data are used in geographic information systems (GIS). The Shuttle Radar Topography Mission is an international project spearheaded by the U.S. National Geospatial-Intelligence Agency (NGA) and the U.S. National Aeronautics and Space Administration (NASA) (NASA, 2015).

2) The ASTER Global Digital Elevation Model (ASTER GDEM) is a joint product developed and made available to the public by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). It is generated from data collected from the Advanced Space Borne Thermal Emission and Reflection Radiometer (ASTER), a space borne earth observing optical instrument.

Presently, there are free available elevation data sets with sufficient resolution for coarse modeling: the Shuttle Radar Topography Mission (SRTM) DEM and ASTER DEM, with 90 m and 30 m resolution, respectively (METI, 2012).

Table 6.2 Character of data and the comparison between SRTM DEM and Aster GDEM (METI, 2012)

Information	**SRTM**3	**ASTER GDEM**
Data source	Space Shuttle Radar	ASTER
Generation and distribution	NASA/USGS	METI/NASA
Release year	2003~	2009~
Posting interval	90m	30m
DEM accuracy (stdev.)	10m	7-14m
DEM coverage	60 degrees north ~ 56 degrees south	83 degrees north ~ 83 degrees south
Area of missing data	Topographically steep area (due to radar characteristics)	Areas with no ASTER data due to constant cloud cover (supplied by other DEM)

The SRTM dataset was generated using a synthetic aperture radar (SAR) system. Whilst the ASTER DEM seem the obvious choice because of its higher resolution, that's not the only control-point. ASTER DEM uses overlapping pairs of satellite images to estimate elevation, atmospheric interference, clouds, sun angle, and other variables which can introduce errors into the estimates (Ibid). Thus, for the water and flood management, the ASTER GDEM is more suitable because of the higher resolution and the higher accuracy.

In the following example, the ASTER and the SRTM image from the data that are available online are compared. In order to design the new artificial Chao Phraya River, the dataset of the elevation is the most important information. Currently, the accuracy that is available for free, is limited (Rees, 2014). In countries such as the US, the U.K and Germany mostly high resolution Terrain Models (DTMs) are already available, whereas in Thailand, it is still not yet possible. The following data compares the SRTM DEM and ASTER DEM on the area of Bangkok including Chao Phraya River (ibid).

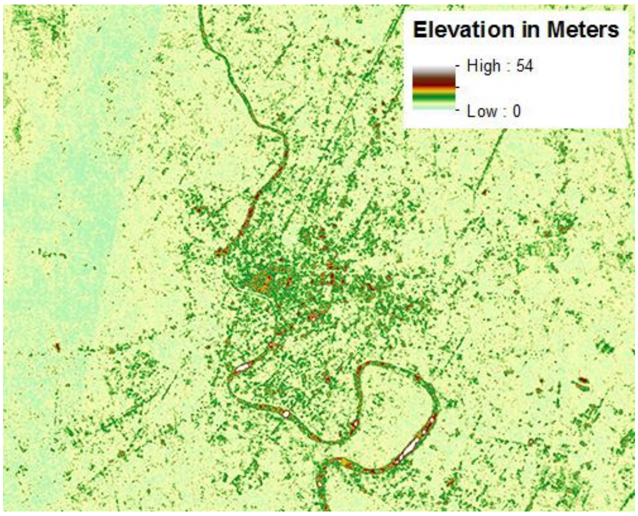


Figure 6.3 Bangkok, ASTER 30 M Resolution (NASA, 2011)

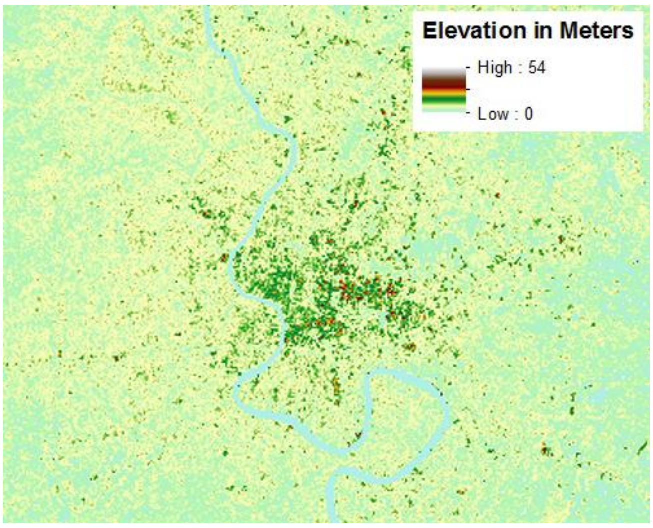


Figure 6.4 Bangkok, SRTM 90 M Resolution (NASA, 2011)

The geographic characters of the area of Bangkok is flat and low-lying with an average of land elevation of just approximately 1.5 m above the sea level.

The figure 6.3 ASTER DEM on 30 m resolution illustrates that in the Chao Phraya River the elevation is higher than the city, which in reality is not possible. From Figure 6.4, the SRTM DEM 90 m resolution data illustrates that the river elevation seems to be more accurate in comparison with the ASTER DEM data.

The conclusion could be, that the NASA SRTM elevation can capture the water feature better than the data from ASTER. However, the ASTER data set has a three times better resolution as the SRTM. The data points that seem to be above the surrounding area along the Chao Phraya River line are possible due to the building and hotels which are located next to the Chao Phraya River.

In cooperation with international Digital Elevation Models (DEM), Germany and Japan already have high resolution Digital Elevation Models available on river basin scales. Even though DEM data of Thailand is available online, high-resolution data of the country is still difficult to achieve. Thai government office such as Land Development Department (LDD) or the Geo-Informatics and Space Technology Development Agency (Public Organization: GISDA) (GISDA, 2016) provide some data. In general, the elevation data is costly for science work.

This research receives a chance for German study supporting and testing with the DEM data from DLR.

6.3 Geodetic Earth Observation

The geodetic works are important for flood management. Especially, Digital Terrain Model (DTM) to design the flow direction and connecting the sub-basin area. The option to gain information on flood risk areas for the works on mapping, design and making a mitigation and adaption plan is mostly exclusively by geodetic measures such as remote sensing, photogrammetry or terrestrial surveying.

6.3.1 TerraSAR-X and TanDEM-X

Herein, the Earth Observation of Germany – the Deutsches Zetrum für Luft und Raumfahrt (DLR) – has developed an intelligent tool called the TanDEM-X mission (TerraSAR-X add-on for Digital Elevation Measurement) which consists of two closely identical earth observation satellites; TerraSAR-X and TanDEM-X (DLR, 2016a).

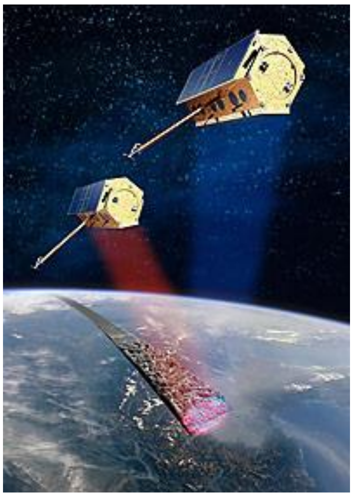


Figure 6.5 TerraSAR-X and TanDEM-X (DLR, 2016a)[35]

[35] Artist's view of bistatic observation by the TanDEM-X configuration; EADS Astrium

Both are equipped with a powerful modern radar system called Synthetic Aperture Radar (SAR). It permits observing the earth's surface not only in daylight but also when it is obscured by darkness and/or clouds (ibid).

TerraSAR-X has been launched on a Dnepr rocket from the Baikonur cosmodrome in Kazakhstan on June 15, 2007. TanDEM-X was scheduled to follow in the first half of 2010. From then on, the two satellites fly in formation in their 514 km orbit (ibid).

The TanDEM-X project is a step that logically follows to the international radar missions like X-SAR (X-Band Synthetic Aperture Radar).

Table 6.3 Mission Parameters (DLR, 2016a)

Launch	First half of 2010
Site	Baikonur, Kasachstan
Launcher	Dnepr-1
Orbital height	514 km
Inclination	97.4221 degrees
Satellite mass	1350 kg
Dimensions	5 m x 2,4 m
Power consumption	800 W
Mission operating	German Space Operations Center, DLR Oberpfaffenhofen
Satellite commanding	DLR ground station Weilheim
SAR data reception	Kiruna (north Sweden), Inuvik (Canada), O'Higgins (Antarctic)
Lifetime	5 years, 3 parallel operation with TerraSAR-X

The mission has the goal of generating a global Digital Elevation Model (DEM) with an accuracy corresponding to the DTED-3 specifications (12 m position, 2 m relative height accuracy for flat terrain.

The central region of Thailand is a flat area which is a challenge for the design of an optimum track of the new artificial Chao Phraya River. As a consequence, it is necessary to use data from Digital Elevation Model (DEM) to support the working process.

In addition, not only the TanDEM-X which provides DEM information, but also the EnMap is one of the most useful data for environmental management which is useful for flood management as well. This research will provide brief information about EnMap on which a future research can built on for flood response planning.

In Germany Deutsches Zentrum für Luft- und Raumfahrt (DLR) – German Aerospace Center (Storch et. al., 2017):

1) TanDEM-X – the Earth in three dimensions
2) EnMAP – Germany's hyperspectral satellite for Earth observation
    - EnMAP (Environmental Mapping and Analysis Program) will be the first German optical earth remote sensing mission in orbit. It will acquire high quality hyperspectral image data.
    - EnMAP may help to find global answers to a range of questions dedicated to environmental, agricultural, land use, water management and geological issues.

Germany's hyperspectral satellite for Earth observation – EnMAP will be launched date in 2017 with a sun-synchronous orbit at a height of 643 km above the Earth, recording data with a 30 x 30 m ground resolution.

Table 6.4 Tandem-X Mission and System requirement (IEEE, 2004)

Mission Requirements	
Digital Elevation Models (DTED-3)	
Vertical Accuracy:	2-4 m (relative)
	10 m (absolute)
Horizontal Accuracy:	10 m
DEM Post Spacing:	12 m
Along-Track Interferometry (ATI)	
Accuracy:	0.01 m/s (sea ice drift)
	0.1 m/s (ocean currents)
	1 m/s (traffic monitoring)
Observation & Operation	
Coverage:	global
Scenario:	mapping of 500 000 km^2 within:
	a) 60 days (DTED-3)
	b) 30 days (~ DTED-2)
Throughput:	100 000 km^2/day (avg.)
	200 000 km^2/day (peak)
Calibration:	avoid reference points in target area
Duration:	> 5 years

Preliminary System Requirements	
Orbit, Constellation & Bus:	
Cross-Track Baseline:	300 m – 2 km (adjustable)
Along-Track Baseline:	< 2 km (for bi-static InSAR)
	200 m – 2 km (adjustable for ATI)
Baseline Measurement:	2-4 mm (without tie points)
Orbit:	polar (i = 97.4°, h = 514 km)
Constellation Design:	reconfigurable (low fuel demand), stable baselines, close formation control, collision avoidance concept (compatible with TSX-1)
System Lifetime:	> 5 years
Instrument & TTC:	
SAR modes:	Strip-Map, ScanSAR as a min. (support of TSX-1 mission goals)
Wavelength:	X-Band (9.5 - 9.8 GHz)
Incident Angles:	25°-50°
Radiometric Performance:	NESZ ≤ -19 dB (@ 100 MHz)
Temporal Correlation:	> 0.9 (e.g. via bi-static InSAR)
RF Phase Knowledge:	< 20°
Resolution (Rg. & Az.):	< 6 m (for 4 interferometric looks)
Pixel Localization Accuracy:	< 5 m
Swath Width:	≥ 30 km
Phase Centers:	4 (to resolve ATI ambiguities)
Downlink Capacity:	2 x 500 Gbit/day (e.g. via second ground station)
Data Compression (BAQ):	2, 3 or 4 bit (or reduced BW)
PRF:	synchronized (for bi-static mode)

(See Appendix 3 for additional information)

The benefit of the TanDEM-X data is providing high quality DEM data for this flood research in the scientific sector. The data is designed for getting experience with SRTM. The potential data can fulfil the requirements of a global scale and high-resolution coverage of all land areas together with the vital information for a variety of applications (DLR, 2016b).

As a consequence, for the case study research; the flood height and height of the terrain are in average about 2 m above the sea level and whereas the terrain of the entire Ayutthaya province is ranging from 1 to 7 m and in the Ayutthaya city center and the historical heritage areas from 1 to 4 m. At this point it will be absolutely worth for the new artificial river track design to use the TanDEM-X data provided by DLR

6.3.2 Earth observation system for flood risk information

One example of the DLR working experience in flood risk management is demonstrated in the region of North-Rhein-Westphalia in Germany.

According to Fischer (2016) a thunderstorm occurred in the area of northern France which then moved to the west and also effected the region of North-Rhein-Westphalia in Germany.

People in Münster and Greven were affected by heavy rainfall which started at 1 pm. The rainfall continued for several hours and the measurements which were taken over seven hours showed a precipitation of 292 ltr. /m^2. In comparison, the average rainfall in that area of the whole year is around 750 ltr. /m^2. Hence this rainfall had massive impacts.

More than 14,000 households were damaged, the roads were submerged in water and the public infrastructure stopped. All in all, the cost of that disaster is estimated to approximately 80 Million Euro. Two people died in accidents and many others were injured (ibid).

Unfortunately, the statistics prove that these kinds of situations are occurring more likely in the future due to changing weather conditions. Not only will the average rainfall per year increase, but also the probability of severe flash floods. Hence, many organizations are trying to estimate areas which are in high risk to prepare counteractions in these locations.

Existing tools for the simulation of flood situation, e.g. from the insurance sector, can correctly simulate a flood along a river, just by following the rule “the farther away from the river, the better protected from flooding”. But the disaster from Münster showed that these tools cannot calculate the more complex risk in the case of flooding from rainfall (ibid).

Therefore, the insurance sector began to cooperate with the German Aerospace Center (DLR) in the year 2013 with the goal of determining new flood risk zones. The DLR however is not using the insufficient hydrological basis information. The DLR relies on the statistical classification and evaluation of terrain data. The principle is simple, water always flows to the lowest area. By following this rule, even the rainfall data of the area does not have to be considered as well, because the influence of it in this case is fractional. The predictions of the DLR were compared with historical flood data and verified an impressive accurateness.

During the first simulation, the mission of the Earth observation Center (EOC) used data from the Indian “Cartosat-P5-Sattelite”. However, nowadays the DLR has access to the most precise terrain data currently available, which was achieved by their own TanDEM-X mission. The TanDEM-X mission provided detailed information of the worldwide terrain which offers the possibility of flash flood calculations on global scale (ibid).

The simulation project of the Earth Observation Center ended in October 2015, while shortly after, many organizations showed interest in the results of the study. Since the end of 2016 this system is used to predict risk areas in Germany.

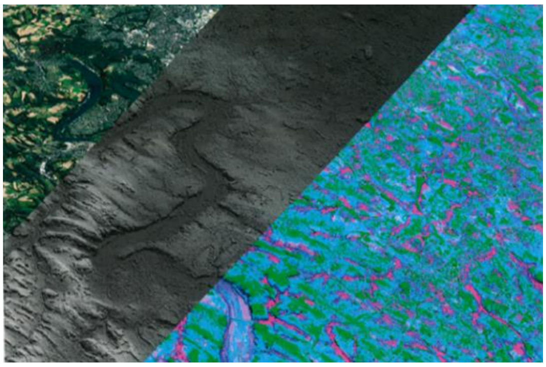


Figure 6.6 Overlay of different Calculation Layers

On the left the Satellite Image in visible light, the Terrain Model in the middle and the Risk Area Calculation on the right (Fischer, 2016).

The new method of risk analysis is not only relevant for insurance organizations, but could also be considered in terms of the planning and design of infrastructure. Furthermore, private households could benefit when those maps are available for free on the internet. Private people could then check if they are in risk and initiate private flood protection measures.

In the meantime, the DLR is using the collected data to develop hazard maps for even more natural disasters such as storms or ground frost. This geo-information has the potential to give valuable information of safe area and areas in risk. That's why the DLR is working closely together with organizations like insurances which can help to optimize the models.

6.4 The need for big scale measures

6.4.1 Option of geodetic development on flood management

The following paragraph is dealing with considerations of impact factors on the flood prevention of the new artificial Chao Phraya River.

For this research, the planning and design guideline of the new artificial river can be divided into three main data-sets which consider physical conditions, social community participation and environmental impacts:

1) High resolution satellite TanDEM-X Science DEM
(German Aerospace Center; DLR)
2) High density and built-up areas
(Public Works and Town & Country Planning, Thailand)
3) Forest covering and land use
(Royal Forest Department, Thailand)

For the final stage, the research anticipates creating a new artificial Chao Phraya River with geodetic approaches and environmentally beneficial landscape.

Additionally, the integration of effective land and water long-term plans will provide increased ability for flood adaptation for communities in Thailand.

- **DEM Analysis of the new artificial river** *(See Appendix 4)*

DEM Analysis of the new artificial river has improved elevation intervals information. The low-lying areas are shown in smaller intervals while the higher areas have less precise intervals.

This is necessary to determine the low differences in the terrain of the plain area of central Thailand. For this research, the higher areas are not of particular interest; hence, grading of the higher intervals has no impacts on the preciseness of the map (Map. 6.1).

The results of the flow analysis were used in the creation of the map (Map 6.2). The simulated water streams are shown which are flowing from high areas to low areas. At the confluence of two streams they do combine to form a larger river line. The bright pink lines show low water flows while the pink lines stand for a higher flow and the dark pink lines for the highest possible water flow. The data (grey dots) show human settlement areas.

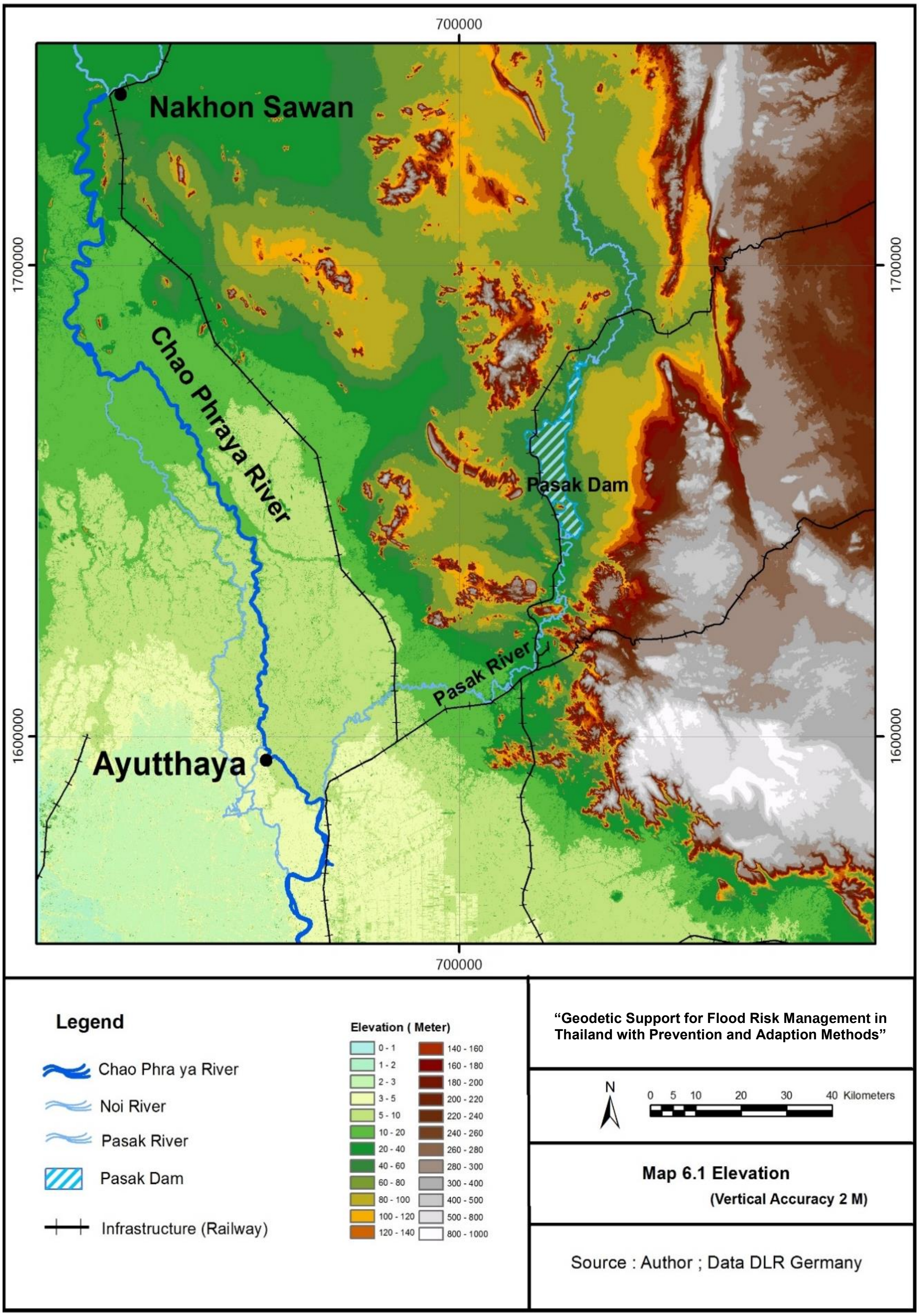
Map (Map 6.3) illustrates the same results of the flow analysis; however, it considers the forest areas (in green) instead of the human settlement areas (as above). It can be seen that in the area of research, less noteworthy forest areas are omitted. This indicates, that in the planning of the new artificial river channel the consideration of forested areas is deemed irrelevant.

The above results from Map 6.4 were combined and lead to the first design of the new artificial river. For these calculation the DEM data of the DLR was used (Resolution 12 m). The line (red) is demonstrated in the map. The first section of the new river channel starts below Nakhon Sawan and flows until Ayutthaya (153.22 km; section 1).

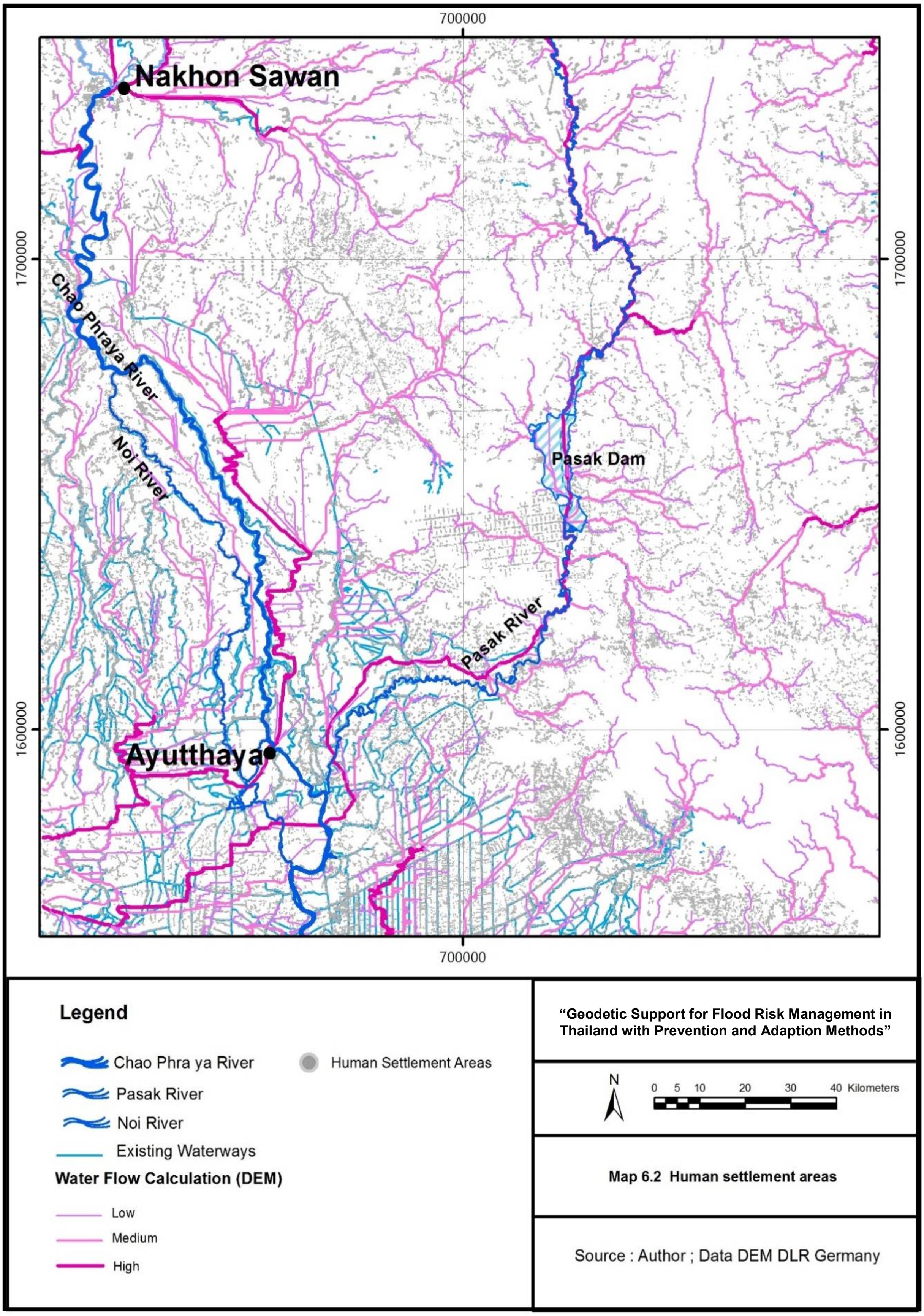
The second section (Map 6.5) leads from Ayutthaya to the shoreline (122.99 km to the Gulf of Thailand). Along this line, the new river line has to avoid areas of high density human settlements, which are numerous around the mega-city Bangkok.

Map 6.6 illustrates both sections on a satellite image of the Central area of Thailand. The length of both sections combined is 276.21 km.

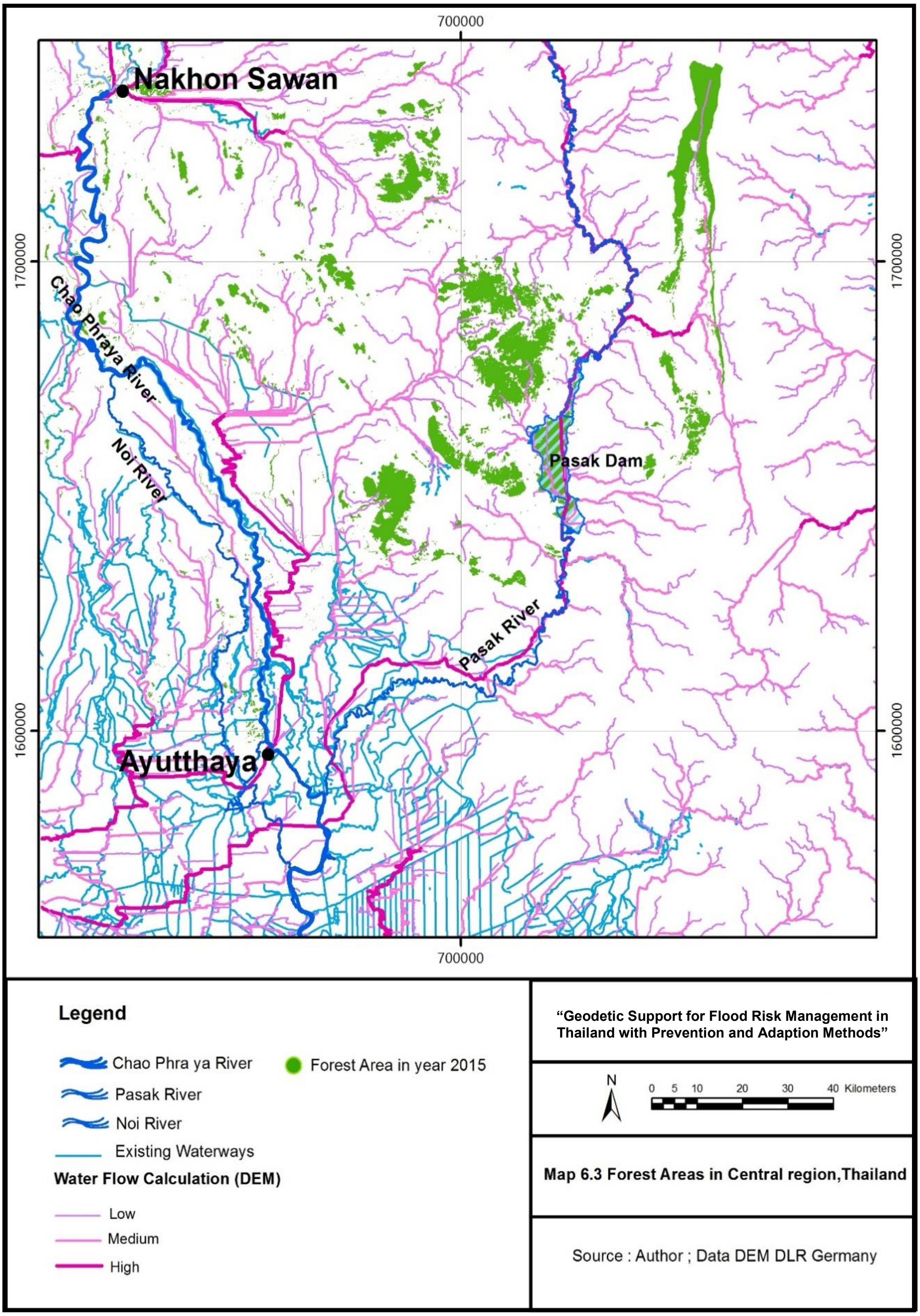
Hereby, the technical DEM analysis can create the lowest track of the river while the socio-economic factors attempt to avoid housings and human settlements; together with environmental concepts which are carefully protecting forests in the prevention area. After the map, the research will explain the cross section design and construction of the new artificial river.



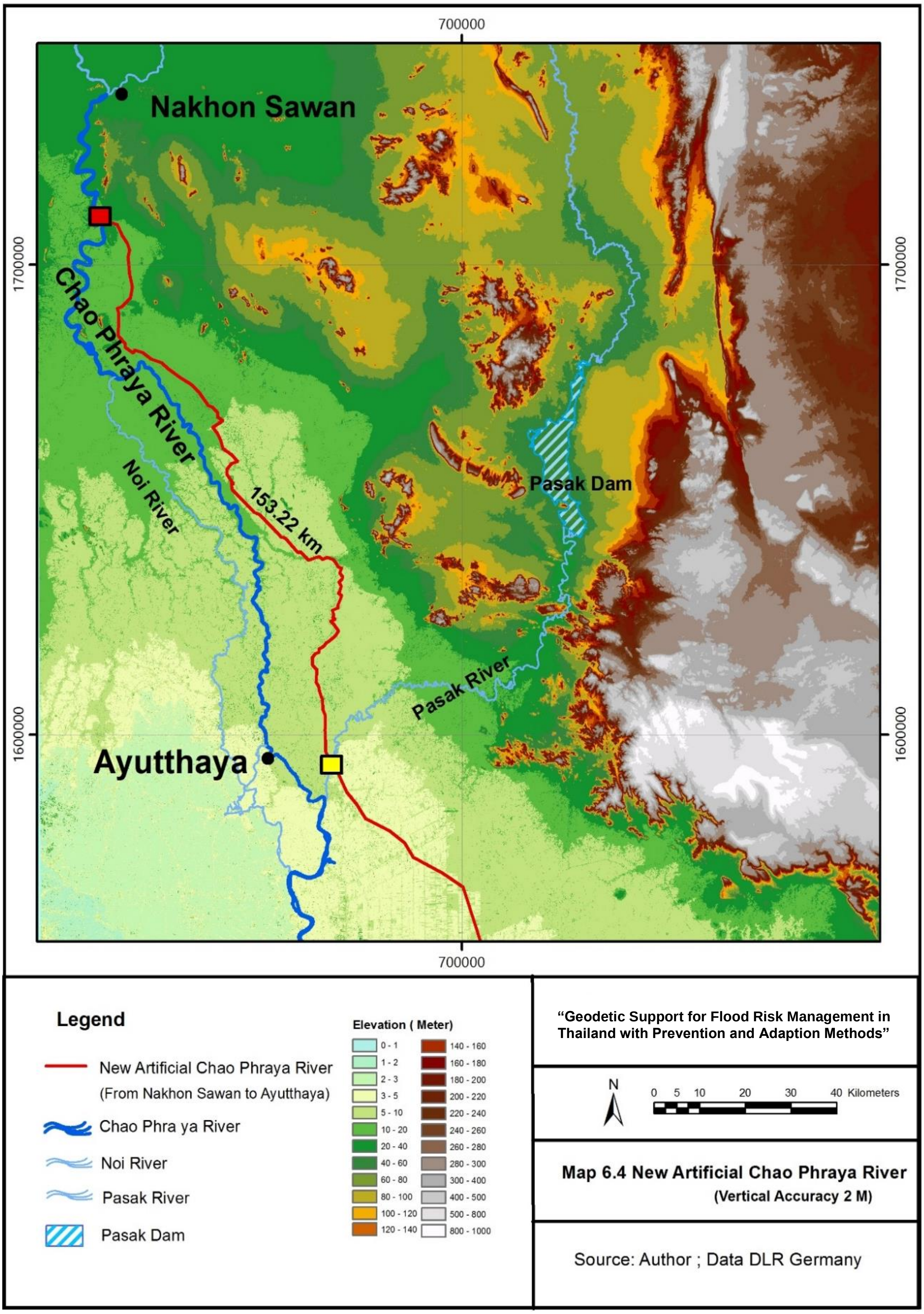
Map 6.1 Digital Elevation Model (DEM) / Terrain high resolution of DLR in case study area



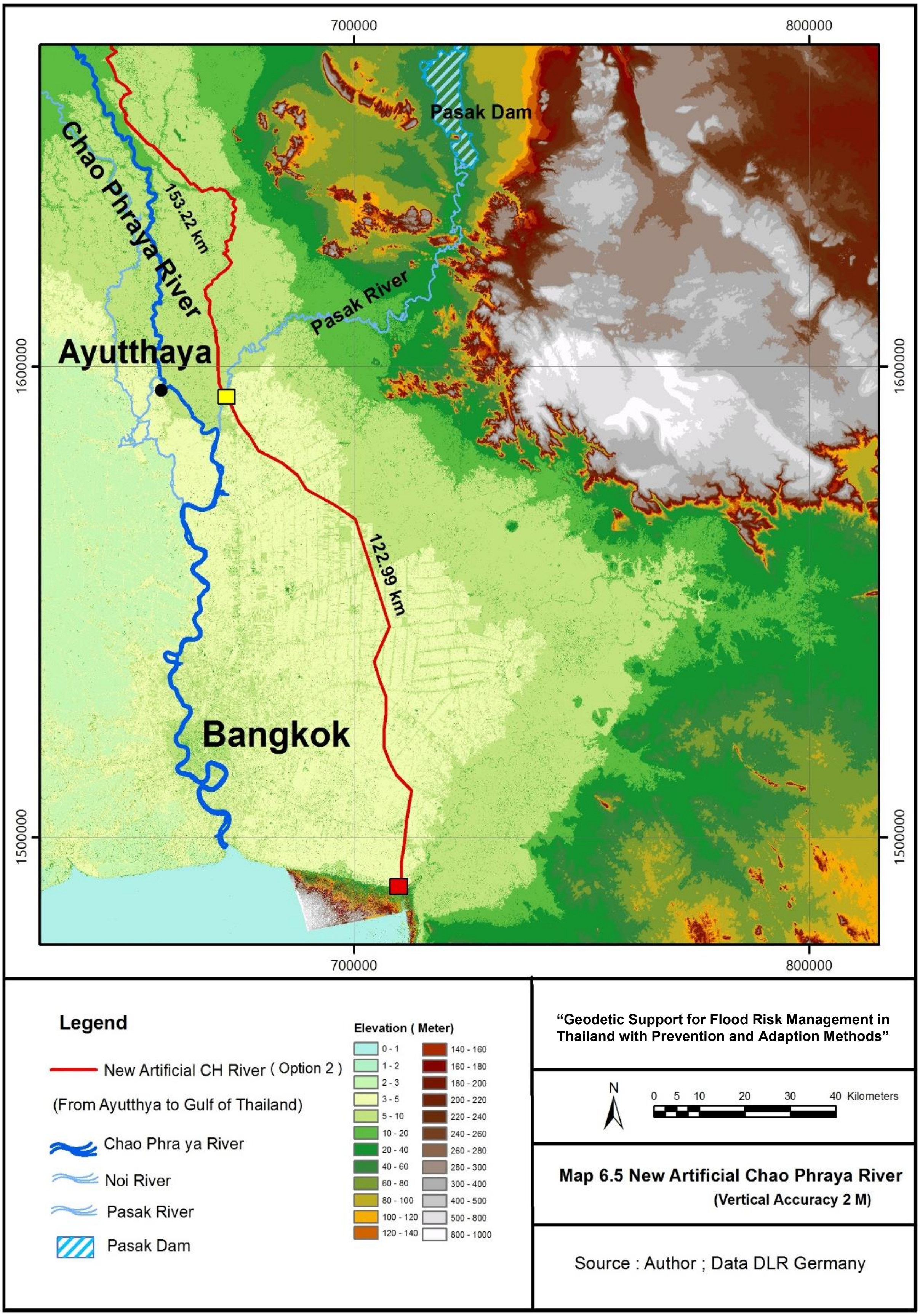
Map 6.2 High density area of Central area of Thailand



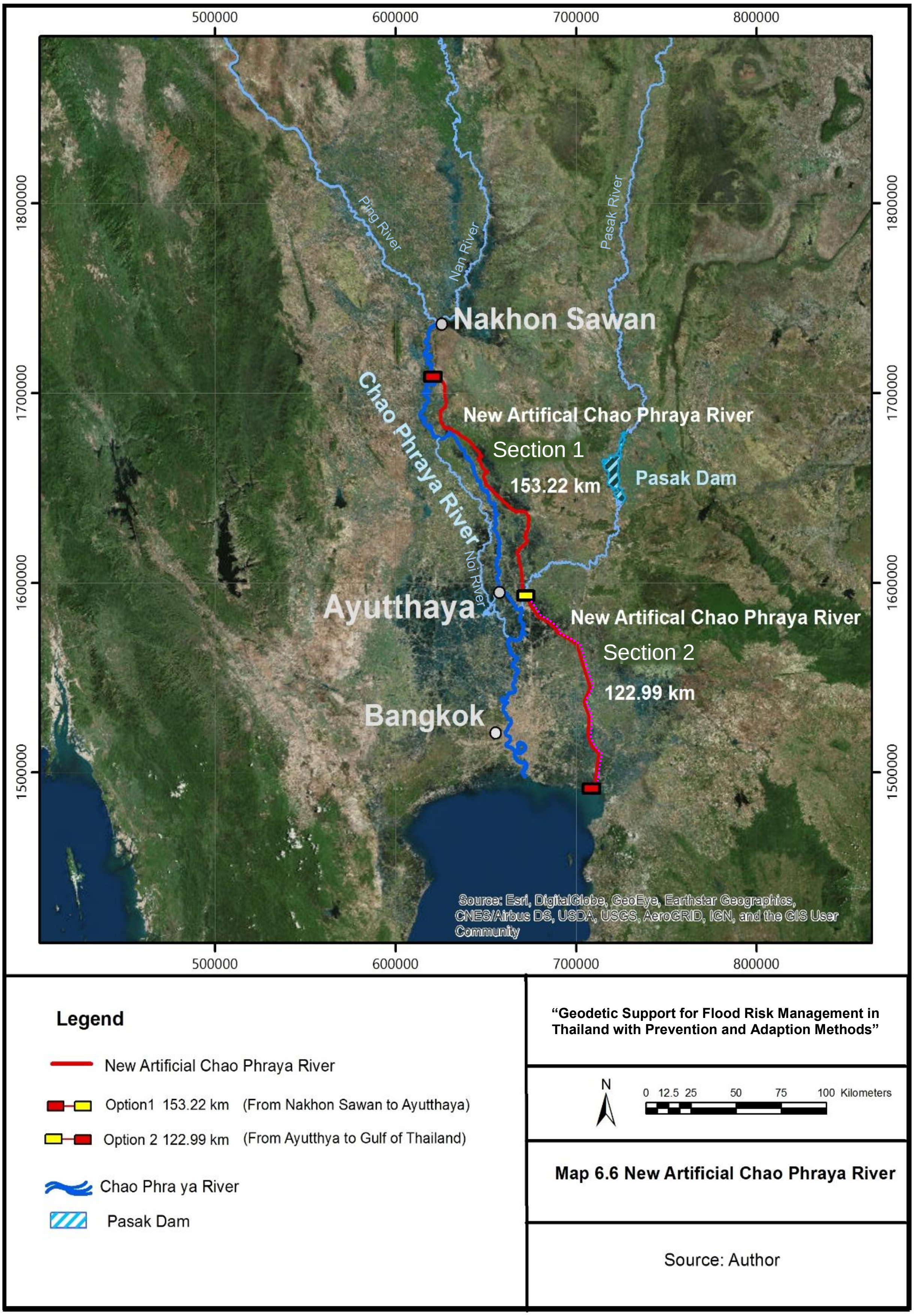
Map 6.3 Forest area of Central area of Thailand



Map 6.4 The first section of the optional channel of the New Artificial Chao Phraya River from Nakon Sawan to Ayutthaya

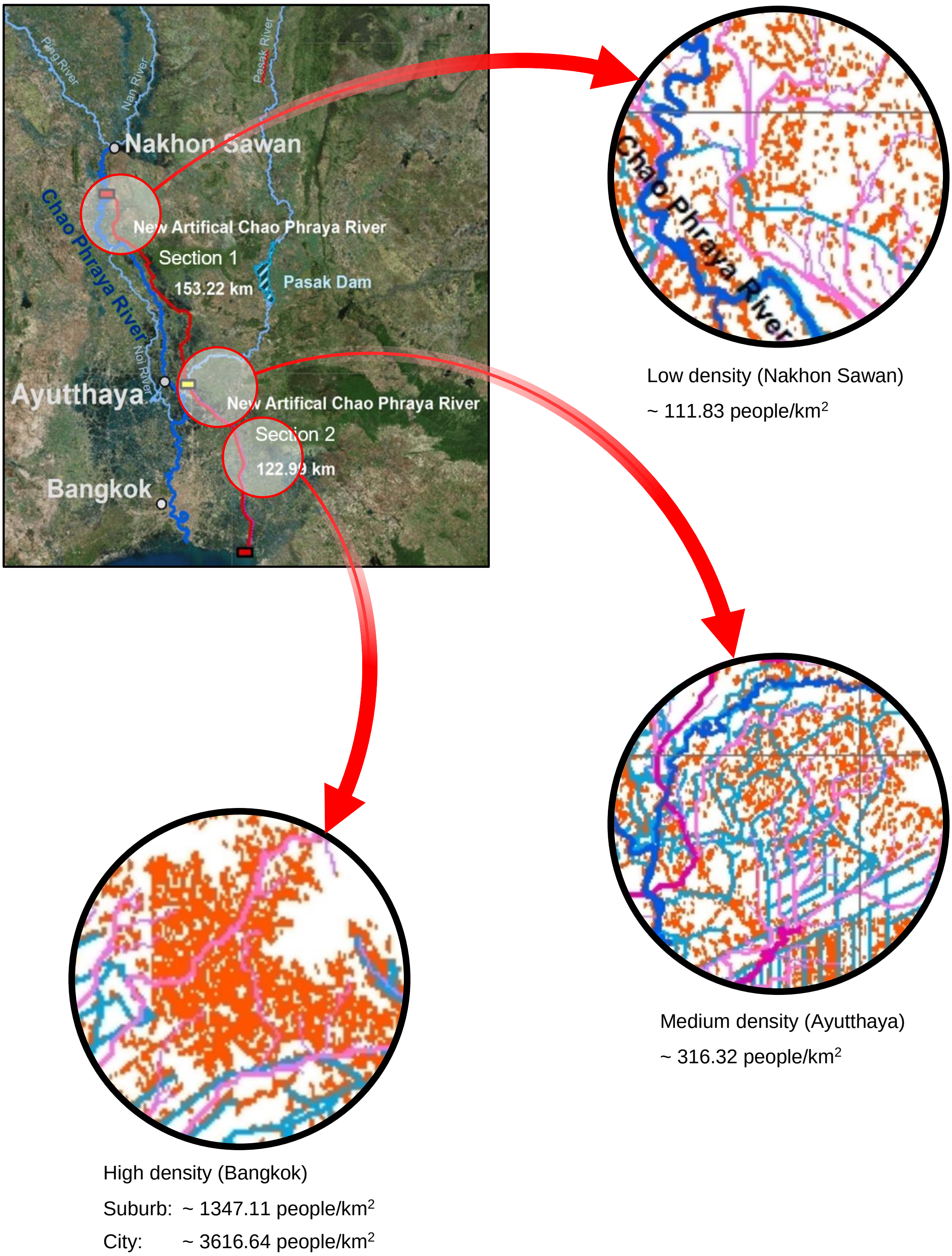


Map 6.5 The second section of the optional channel of New Chao Phraya River from Ayutthaya to Gulf of Thailand



Map 6.6 Overview of the New Chao Phraya River

The population along the new artificial river, has been considered in the design of the river construction. The population data was retrieved from the National Statistic Organization Thailand (2012). The population density can be divided into three levels: low, medium and high. The new artificial river line attempts to avoid high density areas as good as possible.



Map 6.7 Levels of population density along the new artificial river

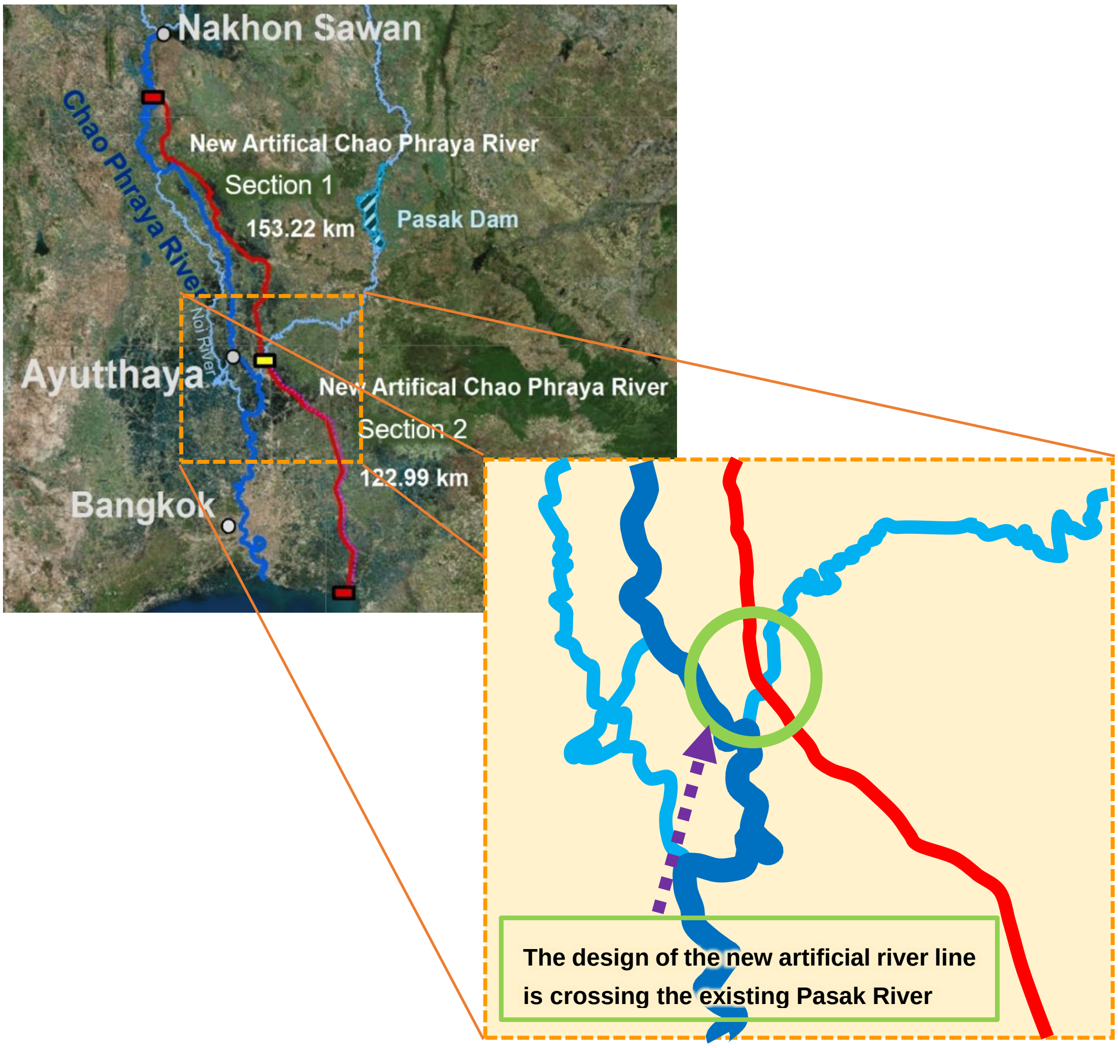


Figure 6.7 New artificial river convergence with the Pasak River

In the design of the new River the area where the new artificial river channel is crossing the Pasak River has to be considered. Therefore, the only possible economical decision may be to integrate the Pasak River into the new artificial river as a tributary.

The old section (present Pasak River) where the Pasak River flows into the Chao Phraya River can be used as a water retention area that also serves communities by collecting surface- and groundwater (See the figure on the next page). Also, a significant amount of biosphere can be preserved ecologically with flora and fauna.

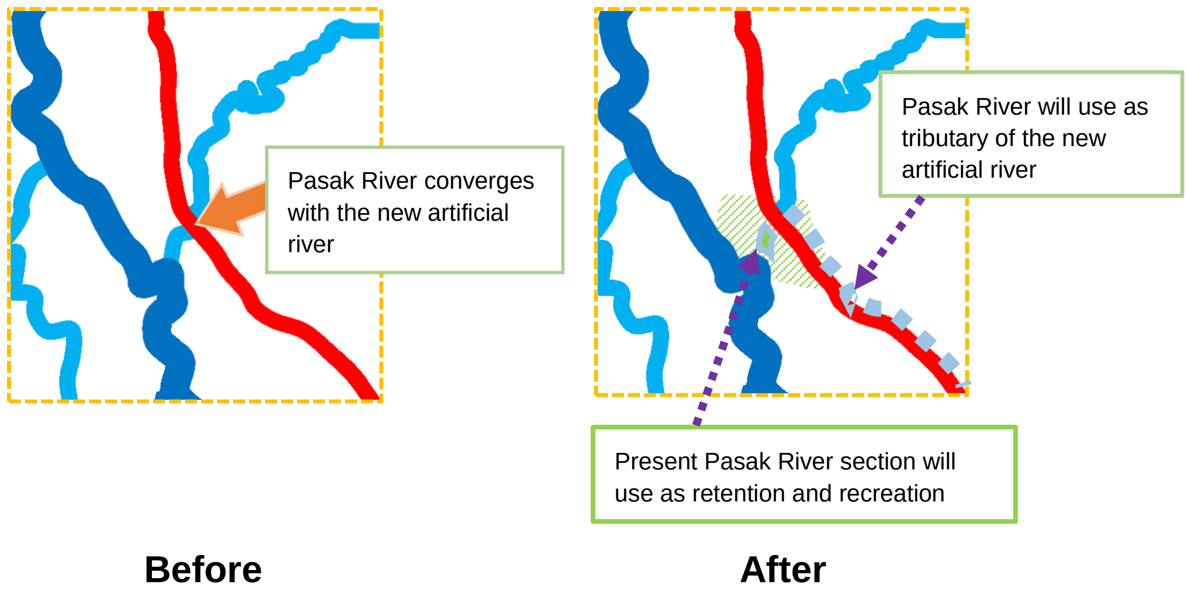


Figure 6.8 Suggestion for the Pasak water retention area

Due to the additional water discharge of the Pasak River, the capacity of the new artificial river has to be designed for that discharge.

6.4.2 River Channel Dimensioning Recommendation

The new artificial Chao Phraya River:

Section one of the new artificial river channel from lower Nakhon Sawan to Ayutthaya city is 153.22 km long. This area has mostly mixed-use activities in the rural area. This research strongly recommends the first section as the main concept for flood prevention, development of land activities and adaptation to climate change.

The section two from Ayutthaya to the Gulf of Thailand is surrounded with high density population and human settlement area. The length of the new artificial river channel is 122.99 km. The difficult circumstances around that area lead to the consideration of two different approaches for the new artificial channel between Ayutthaya and Bangkok. The two options include:

1. One channel with a concrete riverbed
2. Two separate channels with soil riverbeds which split below Ayutthaya. Those two options are described in detail below after the calculation of the sections of the new artificial river line.

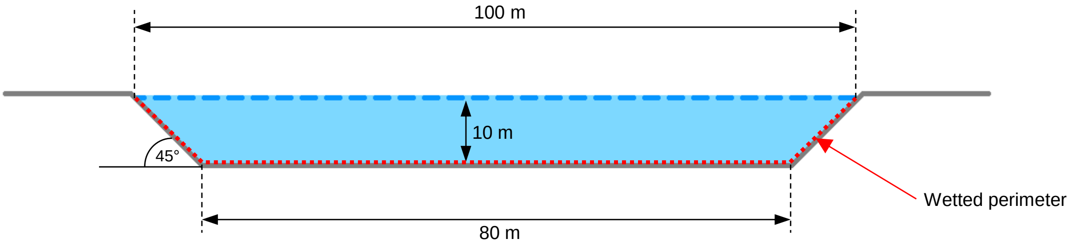


Figure 6.9 The new artificial Chao Phraya River and cross section calculation

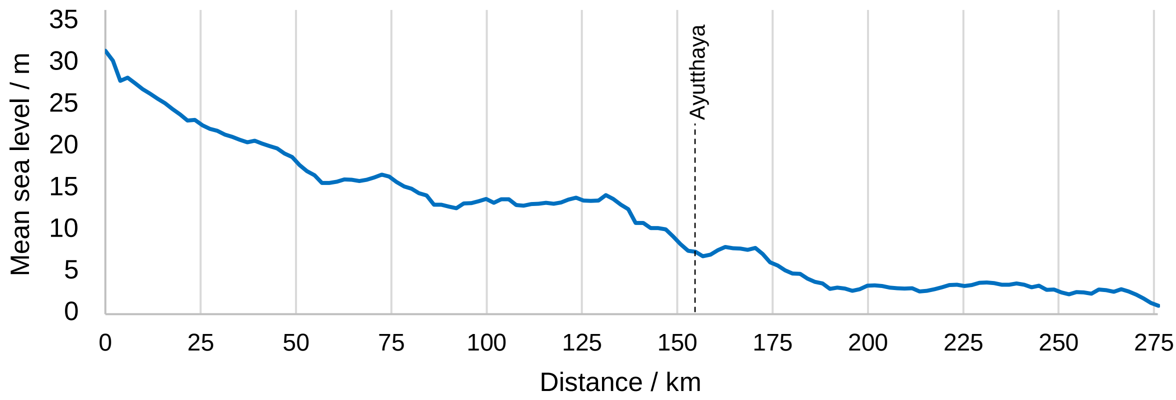


Figure 6.10 Inclination of the new artificial river channel

Used Formulas and given values *(See Appendix 5 for the derivation of the formulas)***:**

River length (l):	*Section 1:* *Section 2:*	153.22 km 122.99 km
Height difference of the river line (Δh):	*Section 1:* *Section 2*:	26 m 7 m
Mean inclination of river (I):	$\frac{\Delta h}{l}$	
Main Channel total width (W):	100 m	
Water depth of main channel (H):	10 m	
Slope of embankment (m):	1:1 = 45°	
Cross section area (A):	$[W - 2 * (m^{-1} * H)] * H + 2 * [\frac{1}{2} * H \; * \; (m^{-1} * H)]$	
Volume of soil/water (V):	$A * l$	
Wetted perimeter (P):	$[W - 2 * (m^{-1} * H)] + 2 * (\frac{H}{\cos(m)})$	
Hydraulic radius (R):	$\frac{A}{P}$	

Coefficient of roughness (k):	*Soil with coarse stone*:	25
	Concrete:	70
Mean velocity of water (ν):	$k * (R)^{\frac{2}{3}} * (I)^{\frac{1}{2}}$	
Discharge (Q):	$\nu * A$	

Option 1:

The depth of the river line in this version is 10 m. The riverbed is made of soil and coarse stones in the first section and concrete in the second section.

First section (Nakhon Sawan to Ayutthaya; Upstream area)

River length:	153.22 km
Height difference of the river line:	26 m
Mean inclination of river:	0.17 m/km = 17 cm/km
Main Channel total width:	100 m
Water depth of main channel:	10 m
Slope of embankment:	1:1
Cross section area:	900 m^2
Volume of soil/water:	137,898,000 m^3 = 137 million m^3
Wetted perimeter:	108.28 m
Hydraulic radius:	8.31 m
Coefficient of roughness (soil):	25
Mean velocity of water:	**1.34 m/s**
Discharge:	**1,202.62 m^3/s**

Second section (Ayutthaya to the shoreline; Downstream area)

River length:	122.99 km
Height difference of the river line:	7 m
Mean inclination of river:	0.057 m/km = 5.7 cm/km
Main Channel total width:	100 m
Water depth of main channel:	10 m
Slope of embankment:	1:1
Cross section area:	900 m^2
Volume of soil/water:	110,691,000 m^3 = 111 million m^3
Wetted perimeter:	108.28 m
Hydraulic radius:	8.31 m
Coefficient of roughness (concrete with timber lining):	70
Mean velocity of water:	**2.17 m/s**
Discharge:	**1,950.17 m^3s**

Option 2:

The main difference of version two to version one is that the river line splits into two lines after the level of Ayutthaya. With two lines, it is possible to construct both lines with soil instead of concrete.

First section (Nakhon Sawan to Ayutthaya; Upstream area)

River length:	153.22 km
Height difference of the river line:	26 m
Mean inclination of river:	0.17 m/km = 17 cm/km
Main Channel total width:	100 m
Water depth of main channel:	10 m
Slope of embankment:	1:1
Cross section area:	900 m^2
Volume of soil/water:	137,898,000 m^3 = 137 million m^3
Wetted perimeter:	108.28 m
Hydraulic radius:	8.31 m
Coefficient of roughness (soil):	25
Mean velocity of water:	**1.34 m/s**
Discharge:	**1,202.62 m^3/s**

Second section (Ayutthaya to the shoreline; Downstream area)

River length:	122.99 km
Height difference of the river line:	7 m
Mean inclination of river:	0.057 m/km = 5.7 cm/km
Main Channel total width:	100 m
Water depth of main channel:	10 m
Slope of embankment:	1:1
Cross section area:	900 m^2
Volume of soil/water:	110,691,000 m^3 = 111 million m^3
Wetted perimeter:	108.28 m
Hydraulic radius:	8.31 m
Coefficient of roughness (soil):	25
Mean velocity of water:	**0.77 m/s**
Discharge per river:	**696.46 m^3/s**
Discharge of *both* river:	**1,392.92 m^3/s**

From the collected data of the previous flooding events, it can be assumed, that this amount of discharge is suitable for a sufficient flood protection of the central area of Thailand.

This research suggest two options for the artificial river lines:

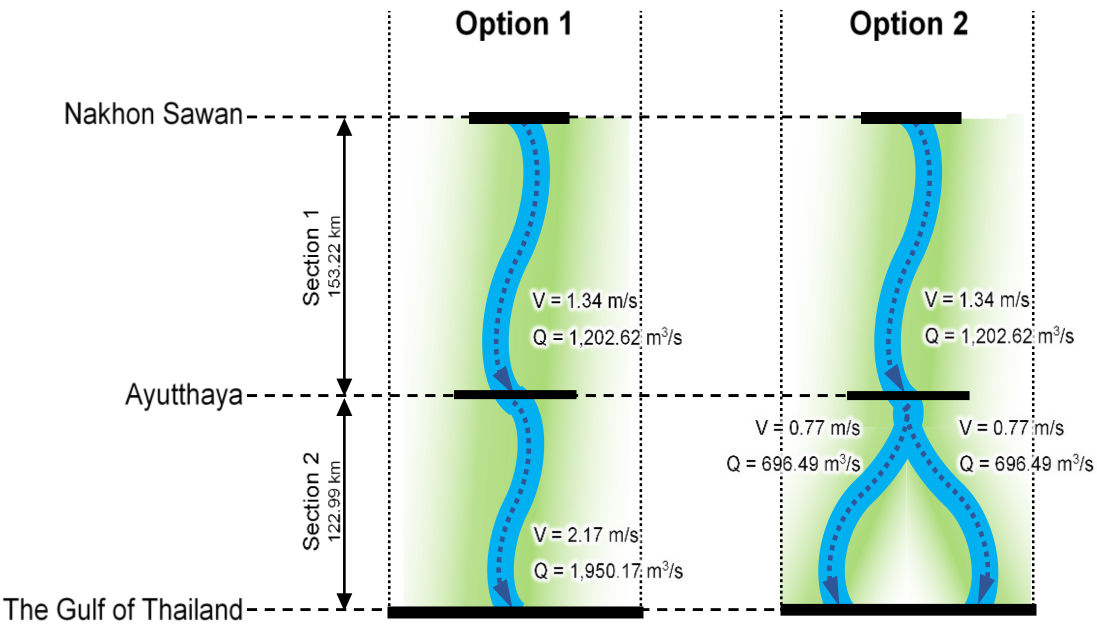


Figure 6.11 Options of the new artificial Chao Phraya River

Option No.1

One continuous river channel, where for the two sections use different materials for the riverbed. For the first section a riverbed use of soil and coarse stone is sufficient for the rural areas, whereas for the second line a concrete riverbed has to be used which increases the coefficient of roughness and therefore the discharge of the channel in urban areas. The second section has to have a higher discharge because of the consideration of heavy rainfall around the area of the river line. Also, the new artificial river converges with the Pasak River, hence it is necessary for the future to prepare an area for high river discharge downstream.

Option No.2

One river channel that leads from Nakhon Sawan to Ayutthaya and splits into two river lines after Ayutthaya. Two river channels have the benefit, that for the riverbed no concrete has to be used. The riverbeds can be constructed with a soil riverbed which decreases the maximum discharge, but with the addition of another channel, the same amount of discharge can be achieved. This option tries to have as less impacts on the natural habitats as possible, hence the soil riverbed and the lower discharge.

The research suggests that section one should be considered as the main support for flood protection, whereas section two in the high density human settlement area is an additional solution.

The slope of the riverbed can affect the soil erosion of the river channel. Hence, in concrete riverbeds steeper slopes can be used. In the following calculation a lower slope of the riverbed in the first section of the new artificial river is considered where soil is used for the river channel.

Example of the **First section** (Nakhon Sawan to Ayutthaya; Upstream area)

- with a slope of 1:3

Slope of embankment:	1:3
Cross section area:	340 m^2
Volume of soil/water:	52,094,800m^3 = 52 million m^3
Wetted perimeter:	103.25 m
Hydraulic radius:	3.29 m
Coefficient of roughness (soil):	25
Mean velocity of water:	**0.91 m/s**
Discharge:	**310.10 m^3/s**

A slope of 1:1 has the benefit of a high discharge, but it also has impacts on the soil of the riverbed. However, the soil erosion can be solved with vetiver grass that strengthens the ground (see Chapter 5.8 Number 4, Vetiver grass / Landslide or Land erosion prevention).

6.5 Review of land and water management worldwide

Land management is one geodetic discipline with a most important equipment to deal with flood issues and other disasters. As this research mentioned in chapter 3 (3.6) Thailand was flooded in 2011, where also one reason for causing the flood was inappropriate land management which involved the land use change, expanding occupations in flood plain areas, land encroachment along the river and irrigation channel and the lack of land use control planning, open spaces, drainage infrastructures, etc.

In the past, the flood prevention constructions were flood defenses such as dams, storage reservoirs, flood walls and flood diversion. However, this research will point out suggestions for a new artificial Chao Phraya River as similar as the flood diversion, specially, in an integrated and holistic approach based on geodetic methods and sustainable land management, with emphasis on harmonization with nature and environmental friendliness.

Therefore, to learn on worldwide practice on land management and flood risk area is essential before providing the concept of land.

6.5.1 Land use planning in flood risk area

The best possible control of land uses in the floodplain area will reduce flood damages and the flood risk offering opportunities for safer occupation of the floodplain. The number of risk bands may vary between floodplain areas depending on the range in depth of the flooding above the flood planning level.

An example from the Australian government suggested an open space area for agricultural land, which can be located nearby the high flood risk area where huge flood impacts will not cause extreme damage and loss of properties. The important hospital utility services should be in a place with zero flood risk.

The Australian government (Graduated Planning Controls) uses a Planning Matrix which shows an example of an alternative approach as flood fringe concept "Flood fringe is essentially the floodplain area remaining after floodways and flood storage have been identified. Flood fringe areas are generally situated around the edge of the floodplain, and the hydraulic impacts associated with development of this land are low, and evacuation to higher ground is usually readily available. This part of the floodplain can be suitable for development depending on the frequency and nature of flooding". More information can be found in (HNFMSC, 2006)[36]

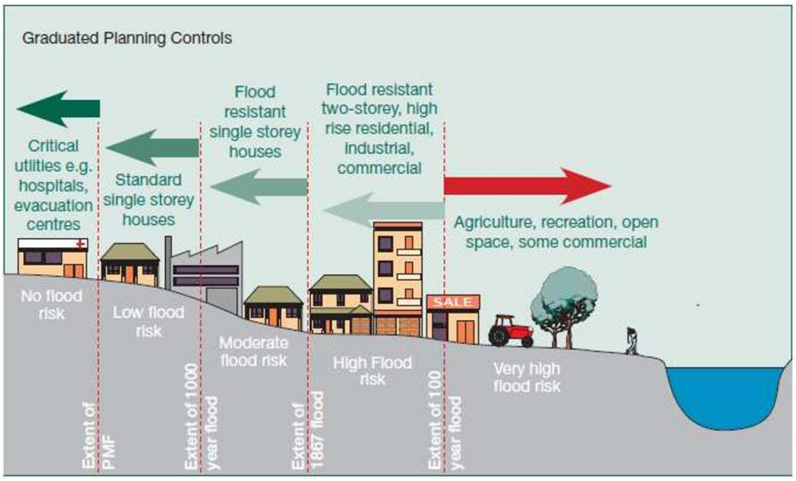


Figure 6.12 The distribution of land uses on the floodplain to reduce risk (HNFMSC, 2006)

In Australia, the complexity of managing flood risks in the Hawkesbury–Nepean catchment is one useful land management guideline. The land use planning and development control measures are an opportunity and solution for different land uses, densities and forms of development.

Likewise, the Ayutthaya province in Thailand experienced the same situation in the flood in 2011, where the hospital had to deal with a lot of flooding problems during the period of flood evacuations.

6.5.2 Facilities of public buildings and infrastructure services

Facilities of public buildings and services need to have more measures to protect this group of buildings when they are located in flood disaster areas. The retrofitting of buildings will work out on private housings and some small buildings, but the way of protection of public buildings will be different from the individual residents. However, public buildings are one of the important services for local people as a place to go for flood victims for evacuation and to use services like hospitals, schools, the fire department, the police station, the government building services, public and private banks and so on.

[36] Hawkesbury's Flood Risk Management Plan: 15 years in the making; adapting a holistic approach to flood management in the Hawkesbury–Nepean region: complexities and perceptions of the agencies.

Practically, the hospital would require moving patients, children and the elderly outside that area to stay safe, when there is no flood protection. Those kinds of public buildings need special protection which is successfully achieved in European countries by having mobile flood protection walls, which can be installed as a boundary along the river.

By the suggestion of the FEMA (2007)[37] on flood proofing residential housings, the strategies were adapted on the basic wet proofing and dry proofing on flood areas. This method needs special consideration from case to case on appropriate areas or high settlements inadequately.

For example, experiences on the Danube in upper and lower Austria show the necessity of mobile flood barriers in areas which are built at predictable water currents. After the floods in 2002 and 2005 settlements were temporarily secured with mobile flood protection (Hochwasserleitwände) along the Danube (Rudolf-Miklau & Rimböck, 2016).

For the improved effectiveness of this measure, the mobile flood walls have to cooperate with:

1) The flood prediction mode
2) The warning und alarm system
3) The organization who is arranging the construction of the walls, for instance, the local fire brigades

Figure 6.13 Mobile flood protection (Hochwasserleitwände) (Rudolf-Miklau & Rimböck, 2016)

Also, many factors may concern the mobile flood barriers as an example in Ayutthaya in the world heritage site and the implementation of it should be much more in the public building in central flood plain areas of Thailand.

Other options for facility services are not only concerning the buildings itself, but the route of transportation which is also important to support the people and being able to evacuate and especially move the children and the elderly outside to a safe area.

[37] Federal Emergency Management Agency (FEMA): Selecting Appropriate Mitigation Measures for Flood prone structures. Washington DC: US Dept. of Homeland Security

- **Bridge constructions**

A bridge can be used mostly for convenience of commercial transportation. Moreover, in case of small floods, the well-designed bridges will help to bring some amount of water to flow more comfortably around the man-made obstacle.

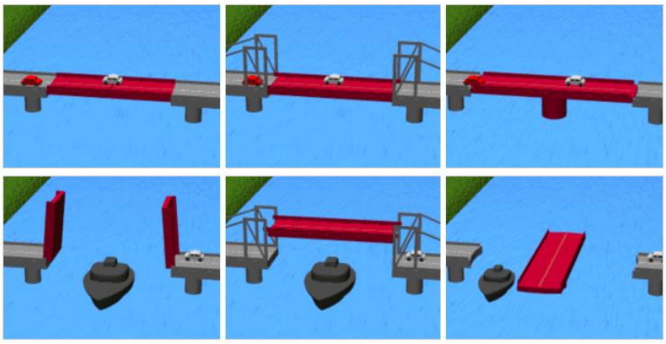


Figure 6.14 Moveable Bridge: (Left) Folding Bridge; (Middle) Lift Bridge; (Right) Swing Bridge (Moveable Bridge, 2016)

The stream of the river especially in the case of a flood can be divided into several streams in different channels with a design of a swing bridge. When letting the water flowing smoothly around the bridge columns, it will reduce the pressure the columns have to withstand. The figure 6.14 shows some alternative designs for bridges, which will not be destroyed during a heavy flood or it may useful for flash flood as well. Because of Thailand knows many natural material made of the bridge on columns and the spacing, thus, the influence of the type of the bridge will be one of factors of consideration.

- **Road infrastructure**

A basic infrastructure will cause more trouble during flooding when the road is the main and only access. For example, road facilities which are linking two areas, representing a paved line, will create flood problems when high impact inundation floods occur for many days. Especially, in the central business districts and / or emergency relief action areas, the situation can be severe. This will cause more problems on the economic development of the country and especially for financial institutions located on this area. From the economic point of view, such a road should also not provoke a negative aspect for transportation. In a case of a severe flood incoming, the road should be possible to either adapt to the new technical design and/ or offer more access from different directions.

As it can be seen in many flood disaster places, many main roads and local roads were cut by the heavy stream of water or high pressure from flood flowing. For example, the flood in 2011 in the Ayutthaya province submerged the main road which made it difficult to evacuate the people and bring them out of the risky flood area.

However, the regarding of the road facility issues is one important part of infrastructural public services.

According to the Pescadero Creek Road project in San Mateo, U.S.A. (2014), some of the suggestions for a solution on flooding that can be applied to the case of Thailand are the following:

- Creation of additional flow capacity at the road through construction of a channel dredging.
- Implementation of upland sediment control activities to reduce the amount of sediment delivered to the flood plain area.
- Reconnection or restoration of floodplains to absorb sediment and flood water energy, thereby reducing the transport of sediment downstream and limiting additional sediment inputs due to incision and bank erosion.
- Restoration or creation of a stable open channel to provide habitat connectivity for local fish and other aquatic species from upstream into the downstream.

The consideration of positive and negative aspects of the interaction between the roads and the flood demonstrates that floods can cause massive damage on the roads, on the transportation function, and beside that, the roads are also causing even more severe floods. This is likely for roads in floodplain areas where they cause an impact on the infrastructure development.

Therefore, the development of the roads in the flood plain will provide more solutions to evacuate flood victims, provide safety places for residential houses and the economic development area will not hamper.

6.5.3 Swiss embankment project (Gotthard-area, Switzerland)

The flood protection in Switzerland along the Reuss River had to be redesigned after flooding in 1987. The lack of available space due to preexisting structures like the A2 highway between Attinghausen and Seedorf along the river presented further challenges that needed to be overcome. Many of the usual methods of retention construction had to be modified due to this obstacle. (Fedier & Walker, 2008).

Solutions to the minimal space problem became a two-pronged approach of increasing the height of existing dams but to also focus on using the existing structure of the highway in practical ways for flood diversions. If massive flooding were to occur that could not be held back by the dams the highway would be closed to traffic for all vehicles. When the highway is clear of traffic a discharge system can then open gates which allows water to flow over the dam onto the highway. The excess water can then flow without blockage on concrete straight to the next lake. (ibid).

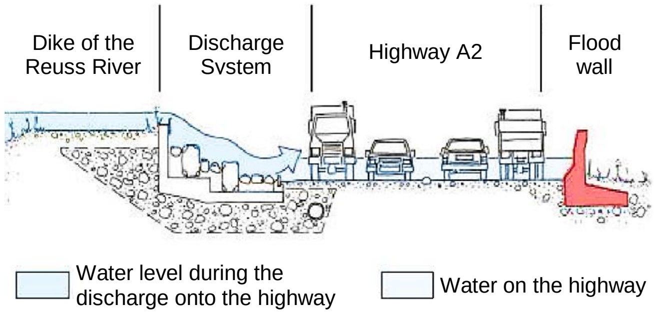


Figure 6.15 Dam along the river Reuss with the highway behind the dam and the Discharge system (Fedier & Walker, 2008)

Discharge system leading the water over the dam onto the highway which is closed for traffic

Before the estuary of the river into the lake, the water must flow down from the highway and cross under another highway. The A4 highway system was reconstructed as a bridge where the water can pass through underneath (ibid).

Figure 6.16 Highway A4 with room for the flood water to flow underneath (Fedier & Walker, 2008)

In more severe cases of flooding events and the over spilling of the flood diversion channel new dykes were built to simply lead the water to the estuary. These dams are not restricting the agriculture but still limit the flow in the affected areas.

This whole flood protection construction reduced the needed water capacity of the smaller Giessen River which is next to the Reuss River. Hence, it now was possible to implement renature measures along the Giessen River (ibid)

Figure 6.17 Before (left) and after (right) renaturing measures (Fedier & Walker, 2008)

The experiences from the Swiss embankment will be useful in the application of transportation and flood prevention at the new artificial river channel.

6.5.4 Enforcement of elevated housing and facilities

Supporting housings and facilities by home owner suggestions to flood resilience

This is necessary for providing the knowledge of local communities which are able to prepare for advanced situations during a flood or for future floods – according to the owners guide to flood resilience, a living document. In the UK, the insurance is becoming a more necessary expenditure for flooding and a more expensive investment. If the people had their own ability and know how to protect themselves from flooding, they would save more, it would be more affordable and they would not have to lighten the load on the own family and would also not bring encumbrance (burden) for government as it is usual in the flooding time. Particularly in the past, the government seemed to be the only hope on responding to flood risk situations for the community (Dhonau et. al, 2016).

In the beginning, basic information will be necessary for example the type of flooding that is occurring in the area of their household's, such as the surface water flooding, ground water flooding, river flooding, coastal and tidal flooding, reservoir or dam failure, bust water mains and sewer flooding. One or more of those types of flooding will attach to the homes of the people. The impact will also differ, for example ground water flooding will mostly only affect buildings with basements. Either river flooding happens followed by heavy rainfall, like the flood in Thailand in 2011. In this case the river flooding seems to be the majority impact on many cities of the central region, because it extends over a very large area causing widespread damage and a long-lasting and difficult to drain flood water problem. A river flooding is jeopardy to household animals and structurally damaging buildings (ibid).

To find out the risk of flooding and the knowledge of how to choose the best option for protection of homes against flooding are still necessary to be consulted with flood experts who can give special advices or consulted with surveyors who have flood risk experience.

For example, the important data that the inhabitants need to know, like the basic information about their floods and what they have to face with is to 1) flood depth 2) flood duration 3) flood onset and 4) flood annual probability. From those four key factors the family can make a decision if they will leave their home (evacuation) or in some cases stay – or they can calculate a time to return back home after evacuation and after the flooding is gone (ibid).

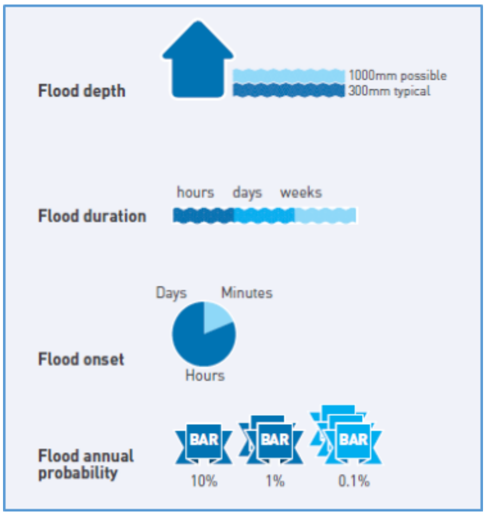


Figure 6.18 Flood information

(Dark blue indicates strong applicability of products in dealing with flooding, with light blue indicating reduced applicability)

The flood information is important to protect people from risks. Facts and data availability should be found at the Environment Agency, local authority and local libraries. Even the local knowledge may need to have specialists supporting them with information and calculation for rainfall, river flow, pipe capacities, measurement of ground levels and etc. First of all, to make a household flood plan it is needed to set up the best emergency actions for flood warnings.

The flood plan will take account of the possibility of flood protection for the households. The UK Environmental agency divided the flood warning code into three levels for specific areas – detailed below:

1) Flood Alert: Flooding could occur and the households have to be prepared to avoid potential harm.
2) Flood Warning: A Flood is expected and the households should take immediate action. A flood warning level is issued and the households should not wait until a severe flood warning is announced.
3) Severe Flood Warning: A severe flood with danger to life is incoming. This warning is issued when flooding is posing significant risk to life or disruption to communities.

Figure 6.19 Flood warning system

Flood warning system is to firstly warn for preparation, secondly the need to take an action to evacuate people to safety places and thirdly severe level of danger by facing with the flood situation. As well as, the device of flood warning should be kept up-to date for different flood situations and there has to be a plan of periodically maintaining the flood warning devices. The local council will be responsible for the specific area of flood warning, which exchanges confidences so the member of the families know what and when to do when the flood occurs. In the UK there is the Met office, which provides a National Service Weather Warning Service (NSWWS) to warn the public of severe weather, including heavy rainfall and communicating it to the public via electronics and broadcast media. Also information for a flood, during a flood and after a flood will be provided by the Environmental Agency and the local council which is cooperating and offering some financial subsidy assistance for flood protection measures through property-level flood protection funding or from other local authority fund (ibid).

To sum up, the home owner guideline to flood resilience is one of the supporting methods for flood prevention and adaptation. The guidelines are providing a lot of products which are suitable solutions for permanent and temporary measures, and resilience measures for single households and whole communities. The home owners can therefore solve flooding problems by themselves or at least reduce the damages on their home buildings. Hence, the home owner flood protection approaches, combined with a well-prepared flood warning system, will significantly reduce the payment of households on flood insurance and also help saving the main budget of the government on managing the flood risk for households and communities with flood resilience methods.

6.5.5 The regulation of evaluated buildings and facilities

- **The social construction in the flood regulation**

In Germany, after the 2002 flood, there were some example cases from the flood protection agency of Saxony-Anhalt. They illustrated how the society can manage the use of floodplains along a river when facing extreme floods. The relationship between the social arrangement and the elemental forces of floods are particularly focused. Moreover, the permitted buildings in floodplains have been mentioned in these projects by involving the Federal Water Act and Flood Control Act directly. Water management, Land use planning and local municipal planning agencies play major roles in approving building permissions in floodplains.

In particular, planning, law and property rights on a persistent social construction, will use the legal framing on the pattern of human activities in floodplain. These majority groups of the social construction are involved in terms of four stakeholders such as policy makers, land use planners, landowners and water management agencies. Those groups will mainly be involved in locating buildings and manage activities in flood plain areas (Figure 6.15).

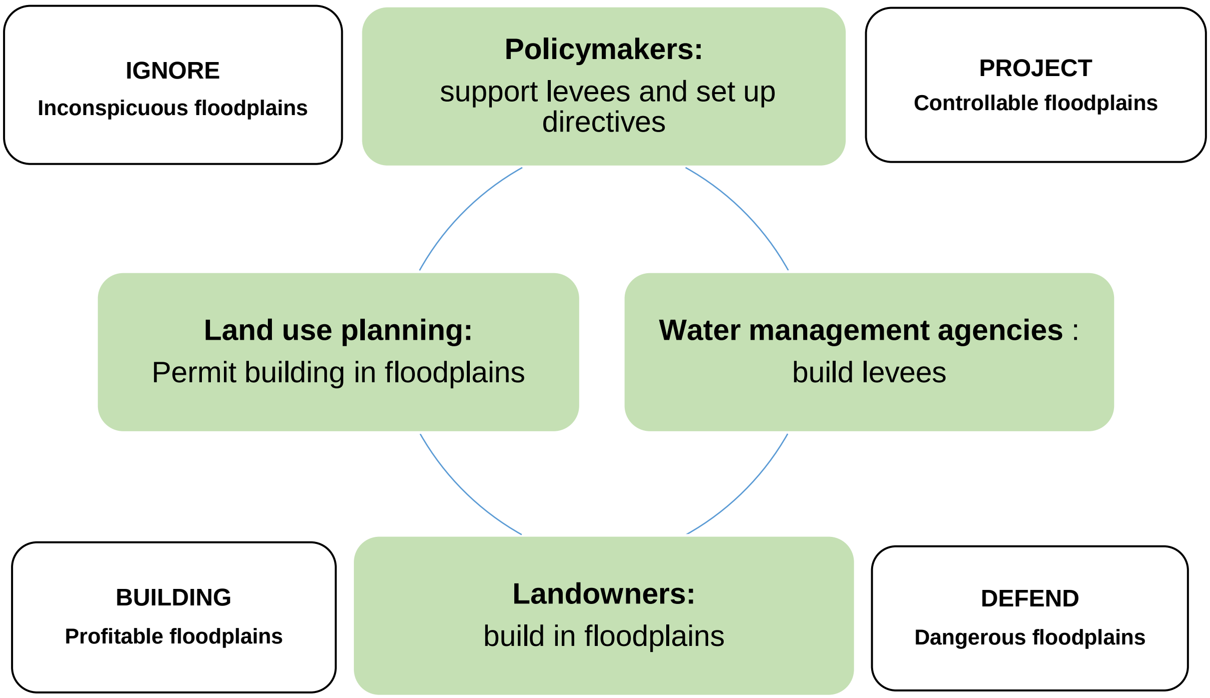


Figure 6.20 Patterns of human activity (EC, 2007)

However, this project tries to develop the measures for patterns of human activity and the social construction of floodplain and for land policy issues on extreme floods. Substantially, it is providing information on better solutions by aiming at the implementing for local communities by connecting Large Areas for Temporary Emergency Retention (LATER) on planning, law and property rights for social construction.

The final consequence is, that the building code of Germany depends on the federal states which are involved in the Federal Water Act and the Flood Control Act. In case to build housings in the risk areas, the individual land owners locating in the floodplains will construct the housing which has to cope with the settings of their own houses in the flood risk locations. The subjective right for protection against financial losses through floods cannot be derived from the law. And the suggestion will be adaptive measures for land owners and local municipality agencies concerning land use planners, policy makers on water management which will combine all of the interest in each stakeholder on implement the flood regulation.

According to Asian Institute of Technology (AIT) and The Economic and Social Commission for Asia and the Pacific (UN ESCAP) (AIT-UNEP RRCAP, 2011 p.7-17) it is reported that many countries contain regulations for buildings with the purpose of improving health and safety of residents. The building regulation is mostly specifying especially the type of materials and techniques. These two options will be suitable to allow the usage in flood risk areas.

Thailand and other countries in Asia and around the Pacific are mostly have building codes. Nevertheless, the system of enforcing the building codes differs from country to country. Besides, it is further mentioned that Thailand has some types of rules on building codes, however, they are exceedingly separated over various ministries and lack of coherency, including, that the enforcement is still not strong enough. Interestingly, many countries in the South and South-East Asia were impacted by massive floods, leaving many homes destroyed and damaged. By the climate change issues, such flooding and the relived loss of life and properties is trending towards happening more frequently. Therefore, incorporating multi-hazard zones and/or special flood prone areas in building code is necessary for migration and adaptation measures and this will be a main challenge for human responses.

- **Challenges of regulation / building code enforcement**

In general, in the regulation of buildings and facilities for flood prone areas the issue of the building code enforcement can be found. For example: German case of regulation on building and building code. According to §903 German Civil Code (Bürgerliches Gesetzbuch), it is allowed for land owners to have a free usage of their property as long as the rights of others are not affected. Restrictions for the use of land are determined by the law (Article 14 1 GG).

The German building code for the buildings in the flood plains does not restrict the rule for prohibiting buildings on the area which could be flooded. Nevertheless, the Federal Water Act (Wasserhaushaltsgesetz, WHG) implemented important laws and regulations on restrictions for buildings in flood prone areas. Furthermore, the Federal Flood Control Act will add more details for connecting with the Federal Water Act. Likewise, the law and regulation are mostly quite different in the individual and depend on the legal application in each of federal states (Länder). Within the harmonized procedures of the flood control Act 2005 of Germany, it is tried to figure out the regional flood planning to support the cooperation on River basins.

Moreover, based on the Water Act after 2005 – which is now reformed by the federal Water Act in 2010 – the federal states (Länder) launched adequate laws to regulate land use in floodplains by regarding to environmental respect with concerning on using the floodplain, restoring floodplains, high water discharge of damage and etc.

Therefore, when buildings have to be constructed in a flood-prone area in central region of Thailand, it is necessary that buildings should be elevated together with the land owners about expected flood levels for at least the design return period to reduce an opportunity of flooding and to limit the potential damage to buildings and it should be suitable with survivability when it is flooded.

6.6 Complementing of land management and the new artificial Chao Phraya River

After the previous lessons learned on flood experience and management measures of worldwide case studies, this research will suggest the new artificial Chao Phraya River as the highlight land management which applies the reviews from topic 6.5 for a suitable flood prevention and adaptation management in the central region of Thailand.

The characteristic of the Chao Phraya River begins at the mountains in the northern part of Thailand. Then, there are areas with water storage options such as lakes, dams and reservoirs. Further, areas for agriculture and farm land, with connections to cities in the central areas along the river like Ayutthaya and Bangkok. And finally, the river ends in the coastal line area of the gulf of Thailand.

For the land management in flood risk areas it can be suggested that the purposes of those areas are different on the vertical line and the horizontal line. Land use activities along the river (vertical line) can be chosen as the idea of vertical land management observation.

6.6.1 Vertical and horizontal land management on a new artificial river

1) Vertical land management concept

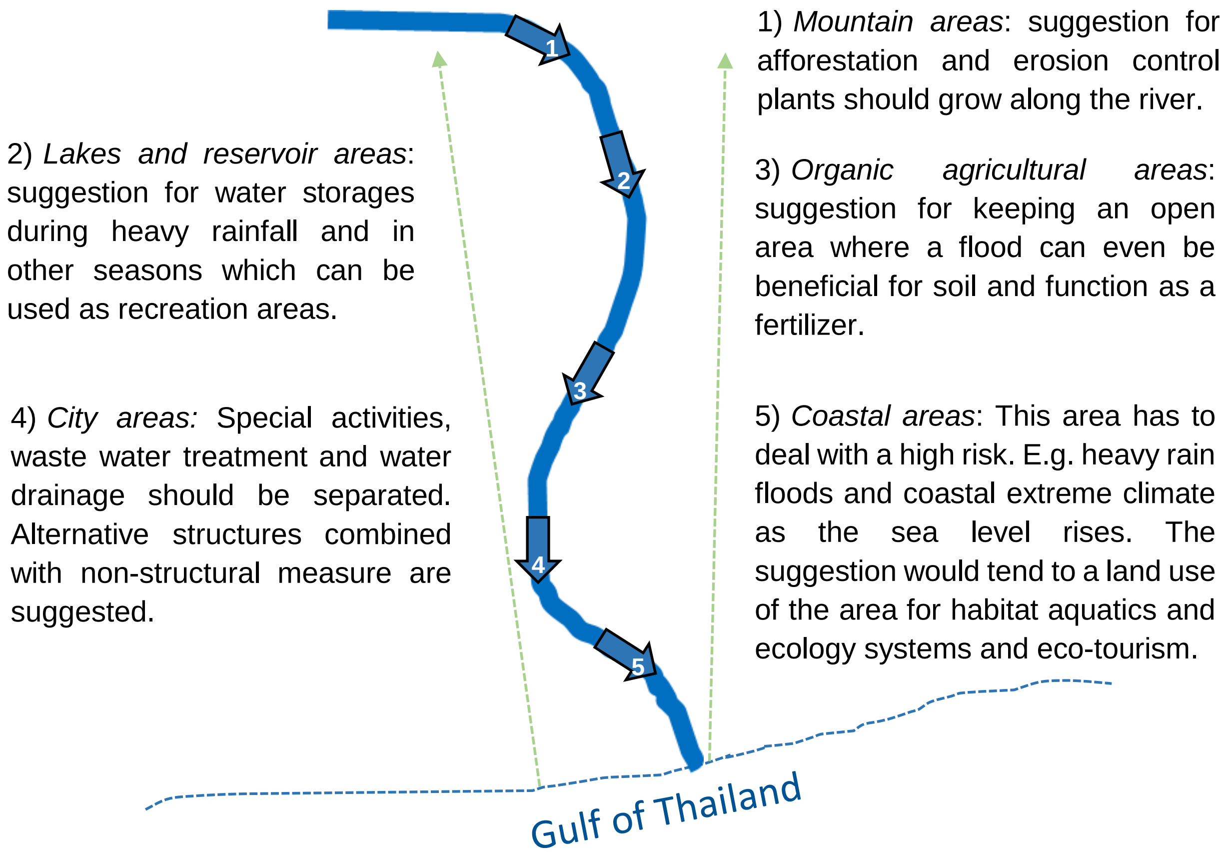


Figure 6.21 Vertical land management along the river (concept) by Author

2) Horizontal land management concept

The horizontal line, representing the area next to the river, should be managed separately for suitable activities. The idea is similar to the concentric zone model of the urban planning which can suggest the beneficial land use in each zone. However, the difference is, that this concept works in the opposite way: The Concentric zone concept starts from the center of the city – the central business area (CBD) – while the flood risk areas start in the center area next to the river as well, where this area should be an open space area and an extended area with the suggestion for the land use to have control zoning for the land activities:

1) Prohibitive zone: The area close to the river should be a setback area. The open space should be kept and it should be not allowed to have new settlements in this area.
2) Restrictive zone: Only special activities of land use are allowed.
3) Warning system zone: New settlements are allowed and can be developed. The concept of the new settlements, however, has to be in harmony with the river and the nature.

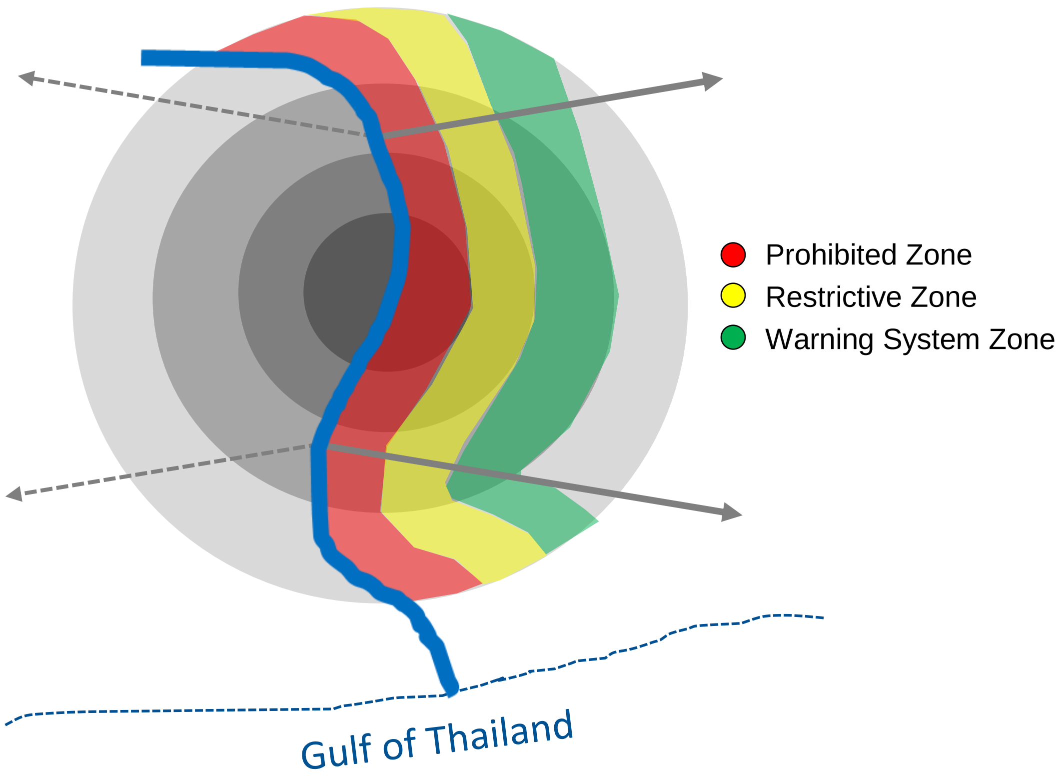


Figure 6.22 Horizontal land management along the river (concept) by Author

From the knowledge about the land topography, which is roughly providing information for supporting a design for a new artificial river, the function and the priorities of the new river will be concerned. The design of a new artificial river requires a lot of consideration on the land management following as:

6.6.2 Land use zoning

For the beginning, the land use zoning can be separated in three zones of different activity along the river:

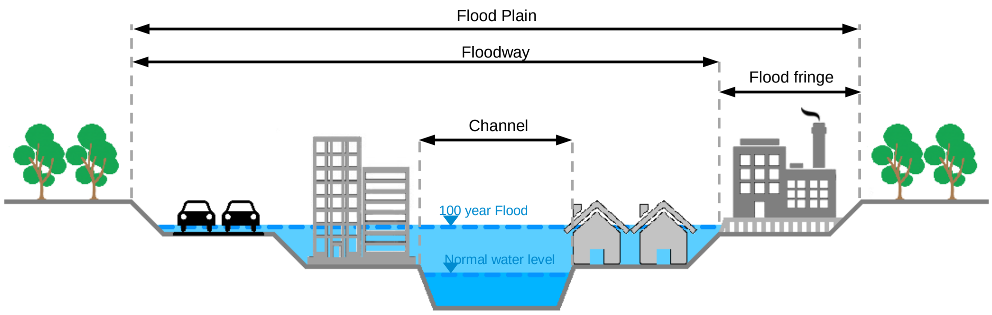
1) Prohibited zone, which will not allow any activities, occurring in the flood prone area.

2) Restricted zone, where activities such as recreational areas, eco-tourism activities, outdoor sports, etc. can be allowed. Based on a 100 year flood (HQ 100). In plan on flood fringe will be the area in between the restricted zone and warning zone.

3) Warning zone, which can be suggested for new settlements or development areas. However, here it is necessary to suggest a temporary building type, for example restaurants with a design that is harmonizing with the natural environment while also suitable for evacuating people when the flood is in coming.

Currently, the land has no key activities, the research will suggest the prohibiting zone, the restricting zone (flood fringe area) and the warning zone or close to development zone:

1. Present situation - *Chao Phraya River*:



2. Future Plan – *A New Artificial River*:

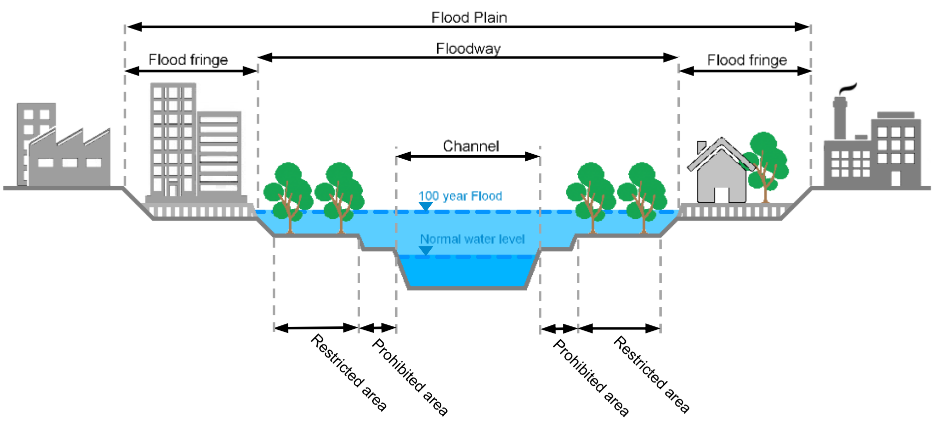


Figure 6.23 An existing land use & land use planning based on a 100-year flood elevation. (Author)

In detail following the future plan (Figure 6.23), based on distance or set-back area in horizontal location of the river line, the research will suggest in the area of prohibitive zone, the first option concerns the new settlements that should not be allowed to locate nearby the area of the new artificial river. Secondly, for the area of restrictive zone that there can only be some temporary construction, easy to evacuate buildings (Evacuation in a short time range).

In the area of the restrictive zone, the buildings allow to be housings with adaptation to the flood plain area. On the next level, on the warning zone, there can be government offices or essential community facilities such as schools and banks where there is warning zone able to response time. The safest area should be reserved for hospitals and other facilities with difficult to evacuate patients and people. This place can also be used for emergency support for flood victims.

3. Future Plan – *A New Artificial River*:

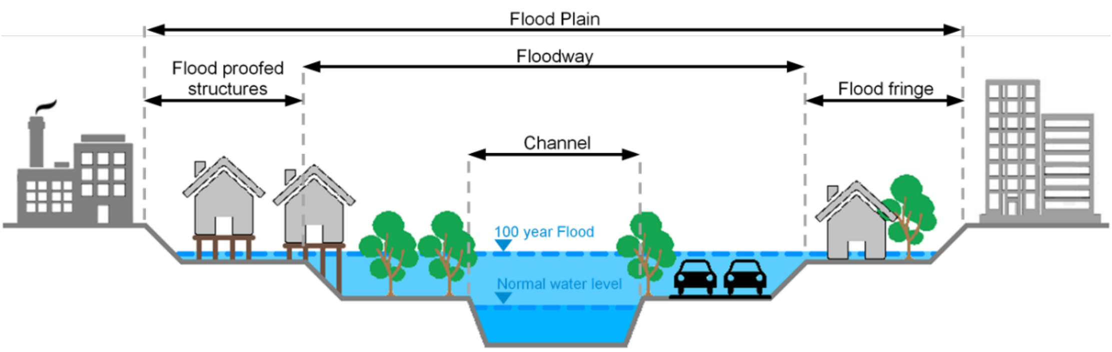


Figure 6.24 Cross section on housing and road embankment for flooding adaptation (Author)

To combine the land use and the land for infrastructure as the Swiss embankment, the new river design concept will combine the embankment and land use zoning along the river.

Hence, the land use in the new artificial river will not offer industrial and commercial zones along the new river. Due to green natural concepts, which will suggest mixed-used traditional & modern agriculture, fascinating natural land spaces and some specific land use activities consider to harmonizing with the nature, from case to case it has to be asked for permissions for the land use regulation.

6.6.3 Building regulation

My point of view on the land management can be summarized in five steps of appropriate land use in practice for a new artificial Chao Phraya River:

1) Protecting the risk from floods by avoiding constructions and accommodations or industries in the flood-prone area or stop developing buildings in the flood basin.

Particularly, in the central area of Thailand the residential and industrial buildings encounter the main risk. These kinds of activity should not be allowed to locate in the main flood risk zone area.

2) Adapting future development on the public infrastructure and the facility communities in the flood prone areas
3) Finding some green space to prepare for the ditches, retention pond or green roofs. This way will be beneficial in the long run. More green spaces in urban and rural areas help absorb the rain water and keep the run-off rates small.
4) Only allow specific land use activities like temporary buildings with easy to handle evacuation in the flood prone areas.
5) Including some adaptive activities which are suitable for the flood plain area.

The new buildings located at flood plain areas have to follow the building code. Especially, hospitals or evacuation buildings should reside at the safest places. For that, land use control and building regulation will be the best solution for that flood situation.

6.6.4 A new artificial Chao Phraya River and land compensation

Nowadays, the main characteristic of the land use of central Thailand, where a new artificial Chao Phraya River will be constructed, is still for residential housing and agricultural area. The new artificial Chao Phraya River is planned to be located through that central part of Thailand. The area requires the compensation of that land for their previous owners. Therefore, the suggestion for the government or the organizations, which accept the project and the plans for building the new river for flood protection and other multi-functional purposes, will be as the following:

1. Compensation of the area where the new river construction will have an impact, with subsidized financial support for land owners of the estimated replacement value.
2. Compensation of the land loss with another land of the same estimated replacement value.
3. Compensation of the standing annual or perennial crops of the estimated replacement value.

From where the new artificial channels will take place, there will be an especially good quality of ecosystems around that area. The suggestion will be to offer land nearby the new artificial river, where due to the build-up of a better environment by reforestation measures, the area will be improved by landscape-related leisure activities (see in the example of The Danube Island).

According to the construction law and regulation in Germany (Baugesetzbuch) the compensation process is handled as described in the following: The process of compensation can be concluded with the government appraising the value of the land where the construction will be located. Then the land owner will either accept the replacement worth in money or worth a land in a new area hence relocation. When the compensation is not accepted by the land owner, the land owner has the right to negotiate on the compensation process. In case the land owner still does not accept the compensation after all, the court will be involved. The court will estimate the land price which the land owner cannot refuse to public authority.

In Thailand, there are some cases, such as the dam construction project of the irrigation department, where compensation has to be done for the land loss of some owners. In that case not only the land of the dam construction has to be compensated, but also the area where the reservoir spreads, such as community and forest land. That project demands a lot of land and it was not easy to find the land for this particular big project.

Therefore, four alternative ways of getting the land were possible for the project:

1. Purchasing the land (similar to compensation by money)
2. Asking for the donation of the land
3. Exchange the land (similar to compensation by relocation)
4. Searching for public land

To explain the purchase of the land in more detail, two types of purchasing the land can be differenced: the purchase of land with a certificate of ownership and without certificate of ownership. The certificate of the ownership belongs to every land owner and is represented by an own title document. The way of purchasing the land can be divided in two ways. Firstly, negotiating with the local community, to find an acceptable price for the land, where both parties can agree on (The Royal Irrigation Department). And secondly, the way of using the law of expropriation B.E 2530 (1987) on the land to be purchased by the government.

For the land without certificates of the ownership such as the public land, this land can be provided for constructions by reporting and reviewing of the Royal Irrigation Department (RID). The construction, e.g. a dam or reservoir project, can use that land when the project will bring benefits for the community. The land of the project construction can be occupied by the Royal Forest Departments (RFD) or some local residents which donate it to public usage.

In that case, the irrigation project does not need to compensate a budget for these public lands and some other project can benefit from the big constructions as well, such as transportation or infrastructure construction or social services for communities.

To sum up, a new artificial Chao Phraya River provides the topic of land compensation with it, this does not only lead to spending the budget for the compensation process, but also to further create more opportunities. Negotiating with land owners and communities will also decrease the budget which will be spent on compensation. Importantly, this research would like to advice like compensation by land in another valuable area rather than compensation by money. This can lead to an improved environment. The aim is to build-up a better environment with the new artificial river than the environment that was there before or was destroyed during the construction.

6.6.5 Structural measures and non-structural measures in flood protection and adaptation

"Flood disaster management is a multifaceted approach and it involves several disciplines such as hydrology, water resource management, economics, statistic, population studies, public policy and planning" (Mohit & Sellu, 2013 p.565)

In order to understand the nature and the impacts of floods, this research suggests measures to reduce the damage. Due to identifying flood hazard areas, the flood damages will be divided into two different areas such as flooding in urban areas and flooding in rural areas. The methods of flood disaster management with structural and nonstructural measures will be suitable with the development area and conservation area respectively.

Table 6.5 Structural and nonstructural flood mitigation and adaptation measures in Thailand

Structural Measures	Non-Structural Measures
• Flood control Dam • Tunnels • Polders/Embankments • Canalization • Flood Diversion Channel or Tunnel • Water retention Areas • Flood walls and concrete panels • Temporary (mobile flood barriers) • Temporary (Sand bags) • A New Artificial River	• Flood risk maps with geodetic data • Land Management and land Use Planning for the zoning in flood risk area • Co-operational integration of river basins • Relocation of local populations • Flood insurance • Forecast and Warning Systems • Guides (Handbooks) for individual households on flood prevention and adaptation of local residents

Therefore, minimizing and implementing the plan of structural and non-structural methods in urban and rural areas can be undertaken through the flowing approach:

1) Structural Approach – the structural approach is based on the engineering measures adopted to control floods or protect human settlements. They include the building of flood wall protection, flood diversion channels, revetments, levees, embankments and others. Or the temporary usage of sand bags and flood wall barrier – commonly used in the flood in Thailand in 2011.

2) Non-structural Approach – the nonstructural approach based on the adjustments of human activities and societies to mitigate and adjust with flood damages. It includes flood insurance, land use management, public awareness, environmentally sensitive area protection and adaption in to other emergency response, recovery and development policies for managing flood damages.

However, for the understanding of major floods in the history of Thailand in the urban and the rural areas, many issues are still caused by social conflicts rather than the flood on its own.

Thus, to create a better way of solving flood problems in urban and rural areas it is suggested to find suitable solutions for each case of structural and non-structural methods. The structural methods apply for the new artificial river, water retention area, polder and embankment. The non-structural methods, however, apply to the land management and land use planning for the zoning in flood risk area and co-operational integration of river basins.

To find a balance between the flood protection and the nature. As a result, these will be better organized flood zoning areas for the land management to solve the increasing flood risks in the future.

Likewise, in urban areas the land uses can be divided into six types (according to the year 2011). There is an average urban area in the central region of Thailand, approximately 15 per cent of build-up area in each city. Peri-Urban is outskirt areas are about 30 per cent of build-up area. The highest density of an urban area is symbolized by Bangkok (2011).

The urban area or build-up area is approximately 63. 93 per cent (Source: Department of Land Development. Thailand)

(1) Residential Area
(2) Commercial Area
(3) Industrial Area
(4) Institution
(5) Transportation
(6) Open Space Area

Rural areas (Data in detailed percentage values from the Land Development Department of Thailand) can be divided in eight different types of agricultural land use of the Central of Thailand:

(1) Rice fields
(2) Farm crops
(3) Perennial plants (Standing timber)
(4) Horticulture
(5) Grassland
(6) Aquatic plants
(7) Forest

Table 6.6: Comparison of flood prevention on structural and non-structural methods for urban and rural area (Author)

Measure/Land use	Structural Measure	Non-Structural Measure
Urban Area	In urban areas, mostly human settlements have hard engineered flood protection with green infrastructures. In urban areas, constructions can be applied for around 70 per cent of the flood risk area.	Creating some space for the need of growing trees and creating green space areas for valued recreational areas. In urban areas, non-structural measures can be applied for around 30 per cent of the flood risks.
Rural Area	In rural areas, it will be better to use less structural applications, due to the adaptation concept of the flood risk management. In rural areas, the structural measures should be methods that are suitable with the flood plain, like the usage of water retention for reducing the flood damage. A possibly ratio of structural measures in rural areas to the total flood area should be around 30 per cent.	An area for the creation of aquatic habitats and maintaining ecological systems with flood adaptation concepts. In rural areas, it is better to keep the nature and benefit from the flood as natural soil fertilizer and vitalization for plants. Around 70 per cent of non-structural measures should be applied in rural areas.

As a result, the flood prevention and adaptation measures to use in urban and rural areas should differ from flood type to flood type[38]. The suitable ratio for flood prevention should improve high density population and low density population.

As a next section, one more approach of natural water retention methods will be the protection of water resources and the management of related risks like floods and droughts. The water resources and the green infrastructures have been improved to connect nature and urban areas by enhanced landscaping.

[38] Flood types depend of the area and velocity such as flash flood occurred near the mountainous area and inundation flood mostly happened in flat area.

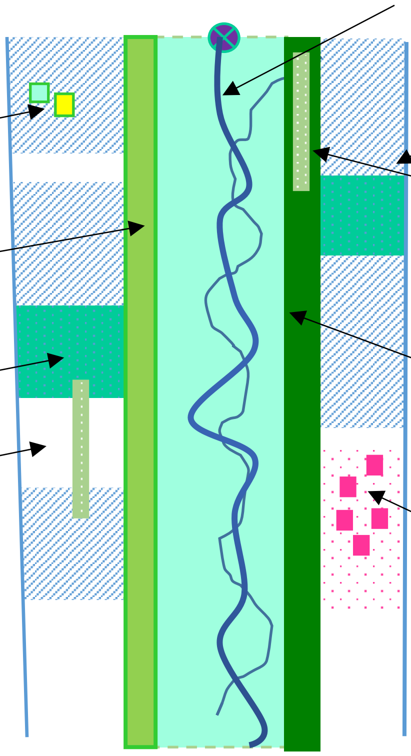


Figure 6.25 Concept of Natural New Artificial Chao Phraya River and Land activities (Author)

6.7 Natural water retention area

6.7.1 Changing land impact to water retention in Thailand

Nowadays, Thailand's natural water retention areas have been changed due to rapid development growth. Especially, central regions mostly transform into residential land and industrial estates. Partial water areas, naturally appearing on the surface, are fast- reducing because of inefficient water and land management. Although this region still has some small retention areas left-over or a few ponds, that remaining water has low quality because of contamination with chemistry and pollution. When heavy rainfalls are coming or the flood season is starting, those retention areas do not provide enough space to keep the water.

As a consequence of changing time, in the past, a lot of open space which was naturally used for water retention helped to not lead to severe seasonal flooding events. Currently, the land use change and more various human activities on water retention area cause more flood impacts. They still have many canals, but the shallow shape and fewer connections between some canals or instead of the roads are the reason why they have not enough capacity to drain the water runoff during flood catastrophes.

4. Future Plan – *A New Artificial River*:

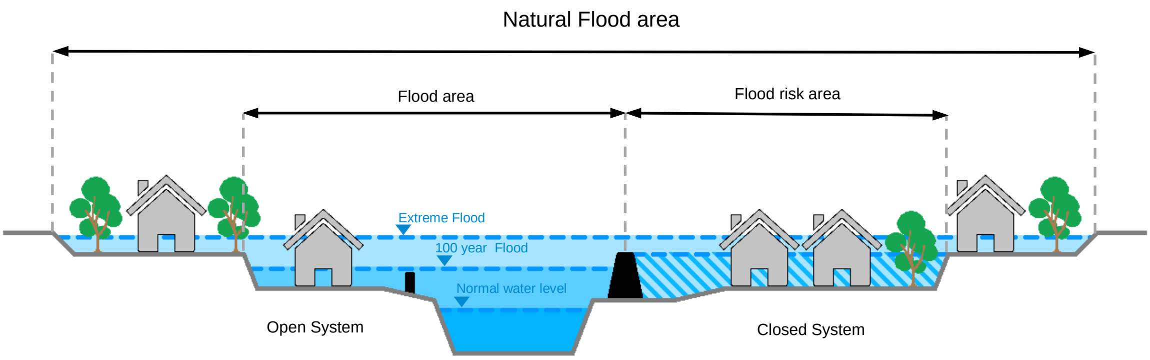


Figure 6.26 Cross section of river with HQ 100 flood (Author)

According to green infrastructures of the European Union (EU) (EC, 2007) - which launched several projects concerning water retention basins - water retention areas play a huge role on water management, disaster prevention and climate change adaptation. The natural water retention method offers the best compromise in terms of social benefits and flood control because the multi-functionality contributes to the cost-efficiency of these basins. Furthermore, it is relevant for many other ecosystem services such as water quality regulation and water provisioning, food or material production, biodiversity protection, recreation, air quality and climate regulation.

Nevertheless, water retention areas which are close to communities need to consider extra critical issues caused by poisonous animals such as crocodiles and snakes. Especially, the Central of Thailand, one of the area which is located in the tropical rain forest country is famous for attracting dangerous animals during the flood period. The concept of water retention areas might create more problem than benefits in some situations. Water retention areas can lead many people to move from their old housing which leads whole communities to re-settlement or relocation.

6.7.2 Opportunities and challenging situations of water retention and water detention in Thailand

Thailand is located in a tropical forest area therefore it is suitable to have water retention basins. This issue is still a huge challenge for the high-density area in cities, however, in rural areas it could be possible to perform the Environmental Act and build Protection area for local communities. The dangerous animals which are coming whilst flood period can be preserved and kept in special zones for them. Communities should have early warning and monitoring systems to not allow people to enter areas like those natural prevention- or wet land-protection areas. Importantly, during the flood season or in the season. That is the way to live peacefully side by side with other creatures on earth.

Sharing natural resources in those areas, especially the basin ecosystem, is one of the challenging sections. In a natural system that has been disturbed by anthropogenic impacts, the ecosystem significantly changed by these factors, and will be continuously pressured by them in the future. Therefore, humans have to change their way of living with other danger species to harmonize the environmental world community.

To summarize, water retention areas have positive benefits and negative impacts. Water retention and detention are two possible choices of flood protection with useful functions like alleviate and reduce the damaging effects of river flooding and seasonal flooding.

The suitable solution to use water retention and detention areas is by providing spaces to both sides of the river where flood water can be released into. In my opinion, the main solution for the flooding problems will bring the new artificial Chao Phraya River.

5. Future Plan – *A New Artificial River*:

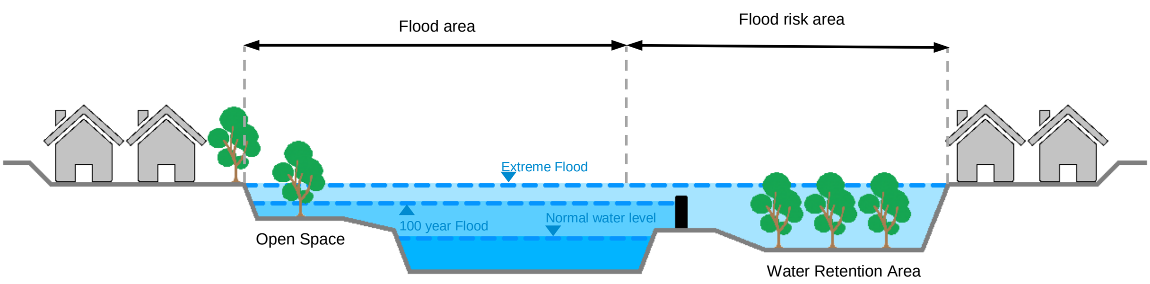


Figure 6.27 Cross section of New Artificial Chao Phraya River with water retention (Author)

To have water retention areas will support the flood protection even more, while also providing water storage for the local people in droughts for the local consumption and offering benefits for recreation areas and aquatic eco-systems. Having cooperation with the local administrations among the cities where the river will pass through with shared responsibilities for the water retention areas will develop the ability of the decentralization of the responsibility system for having the geodetic approach for the water and land management.

6.8 Chapter Summary

This research will suggest a new artificial river as being the most valuable approach for flood management measures in Thailand. The planning for an artificial Chao Phraya River that will maintain the environment and minimize relocation of the local residents is a desirable outcome. The material of river construction will recommend the natural roughness (from the theoretical calculation). Also, this research has illustrated the use of new technology such as “Radar”-satellites to find a suitable and safe way for the new river through higher risk areas of the central flood plain in Thailand. By connecting the higher risk areas that are laying at the lower levels a new line for the river can be created. That line will be created where the safety areas are rearranged as settlement zones and forest areas. Advanced satellite technology utilizing geodetic methods will support the first steps for the design of the new artificial Chao Phraya River.

Secondly, water retention areas will be considered to support the flood risk management. In the past, many of the natural retention areas were located in the central area of Thailand. Finding natural retention areas for re-habilitation and using modern land management for dividing suitable areas in each city (on ratio along the river passing) for the use of flood water storage, are necessary steps of the flood management processes. Additionally, land management with the geodetic approach will support keeping harmonious balance between the ecological systems near those retention areas. Also, the suggestion for the future works can be planned via mapping 3D features in Open StreetMap-ArcGIS (OSM) for flood prevention and modelling the risk of flooding in the future.

Thirdly, the cooperation between the national and the local government has to be strong. One agency from the environmental department can be responsible for the projects for flood risk management while another department can work in cooperation of flood adaptation. Most importantly, the local government will represent the base movement to maintain the flood risk management for the local communities. The national government can provide the measures, however, in practice the local government will mainly take action in the field work. The constantly changing positions in the administrative system will keep the project running and maintain the river in the future. Hence, the local people and the committees will play a crucial role in leading the projects to their completion while working hand in hand.

Climate change and human-made floods are an extreme situation. There is, however, a common awareness about the need for adaptation and preventative awareness of disaster to the population. The extreme situations due to climate change lead to more flooding and furthermore the enormous flood protection measures created by humankind will have even more impacts on some local community in many ways. Therefore, the investment in the new artificial Chao Phraya River will be a valuable asset for the future. Having environmentally friendly concepts of flood prevention and adaptation while creating more recreational use areas is a positive step in that process. In conjunction with providing more open space and wider areas of nature for local communities will be the best solution for Thailand.

The most important of all is the need for mutual cooperation amongst surveyors, city planners, and water and land managers. In order for the project to flow smoothly there will be a need for shared trust and understating that it is in the best interest of all to find a synergy so that all can be satisfied. The practical and aesthetic needs of many can and will be fulfilled by this positive advancement.

Item	Solution concept	Description	Benefits	Obstacle	Short term	Long term
1	**New artificial river**	Creating a new artificial river channel to continuously discharge an additional amount of water in a separate channel which is seamlessly design into the nature	**Technical:** • Can discharge a huge amount of flood water without risks **Economic:** • Income from tourism in newly created recreation areas along the artificial river channel • Suitable investment **Social and Political:** • Public activities along the river in recreation areas which will encourage a sense of community and well being **Environmental:** • Environmental friendly (designed naturally) • Promote amenity and diversity	**Technical:** • Huge amount of excavation mass movement • Soil erosion has to be considered **Economic:** • Suitable one-time-investment **Social and Political:** • Relocation of people **Environmental:** • During the time of the construction, there will be disruptions to some parts of the environment		**X**
2	**Diversion channel (Bypass/Tunnel)**	Drainage of a huge amount of water for a limited amount of time in a hard engineered concrete channel.	**Technical:** • Possible rapid discharge of flood water **Economic:** • Can quickly counter impending flood damage **Social and Political:** • For tunnel (underground construction thereby reducing the need to relocate people) **Environmental:** • -	**Technical:** • The construction can be damaged easily over time which could lead to even severe emergency situations in the case of a failure **Economic:** • High investment **Social and Political:** • Relocation of people **Environmental:** • Permanently destroying ecological systems • Impact underground water		**X**

Item	Solution concept	Description	Benefits	Obstacle	Short term	Long term
3	**Water retention**	Increasing the water storage in emergency situations around communities.	**Technical:** • Can be adapted for big and small scale (depended on urban and rural areas) • Can store fresh water during the dry season **Economic:** • Low investment **Social and Political:** • Possible recreation area and public activities around the water retention area • No relocation necessary for small retention areas **Environmental:** • Aquatic creatures friendly • Promote amenity and diversity • Landscape improvements	**Technical:** • Large amount of land is necessary for the construction **Economic:** • Expensive land has to be purchased or compensated. in urban area **Social and Political:** • Relocation of people in large scale water retention areas **Environmental:** • Poisonous animals will be attracted to the area which could conflict with human activities		**X**
4	**Land management**	Land use control and zoning areas (restricted areas, prohibited areas and warning areas).	**Technical:** • Ecological protection of the environment • Land readjustment can be implemented in urban areas • Land consolidation can be implemented in rural areas **Economic:** • Low investment **Social and Political:** • Human settlements and properties are located in safe areas • Flood act will be applied **Environmental:** • Creates open spaces for urban areas • Maintains farmland near by the flood area in rural areas	**Technical:** • Difficult implementation in practice because of law and regulations **Economic:** • Investment in education and knowledgeable management has to be fulfilled **Social and Political:** • All stakeholders have to participate equally. This can lead to conflicts **Environmental:** • Difficult implementation in urban areas (lack of open space in urban areas)		**X**
5	**Flood cooperation**	Communities will support to keep flood management projects ongoing.	**Technical:** • Technologies like flood forecasts and warning systems can be used together **Economic:** • Low investment **Social and Political:** • Communities are sharing flood information and are able to help each other in emergencies • Raises awareness and enhances the preparedness on flood risk **Environmental:** • The nature atmosphere diversely created	**Technical:** • The cooperation will not work with one single command **Economic:** • Business meetings consume budget **Social and Political:** • Conflicts in the social interactions can occur • Overlapping working tasks **Environmental:** • Conflicts in politically interested parties can occur		**X**

Item	Solution concept	Description	Benefits	Obstacle	Short term	Long term
6	**Flood barrier**	Mobile and temporary flood protection measure to withstand the flood water for a limited amount of time (e. g. sand bags, mobile flood barriers)	**Technical:** • Quick setup **Economic:** • Low initial investment **Social and Political:** • - **Environmental:** • The construction itself has less impacts on the natural habitat	**Technical:** • No permanent flood protection. • Cannot withstand huge flooding **Economic:** • High maintenance cost • No one-time investment, but temporary protection has to be purchased for every single flooding event **Social and Political:** • - **Environmental:** • After the usage of a mobile flood barrier damaged parts can be left to nature	X	
7	**Flood wall protection**	Private or public permanent flood walls for the protection of land and property	**Technical:** • Strong structure that is not easily damaged • No high investment for planning the structure **Economic:** • - **Social and Political:** • - **Environmental:** • -	**Technical:** • Makes the river narrow • Doubles the possible damaged in areas that are not protected • The construction has to be continuously monitored **Economic:** • High investment for the construction • High investment for the maintenance as well **Social and Political:** • Separates people (lack of social interaction) **Environmental:** • Destroys the environment permanently and has impact on climate change in the long run	X	X

Part 1 Summary: Flood Solution Concepts

Part 2 Summary: Three dimensions of flood risk management

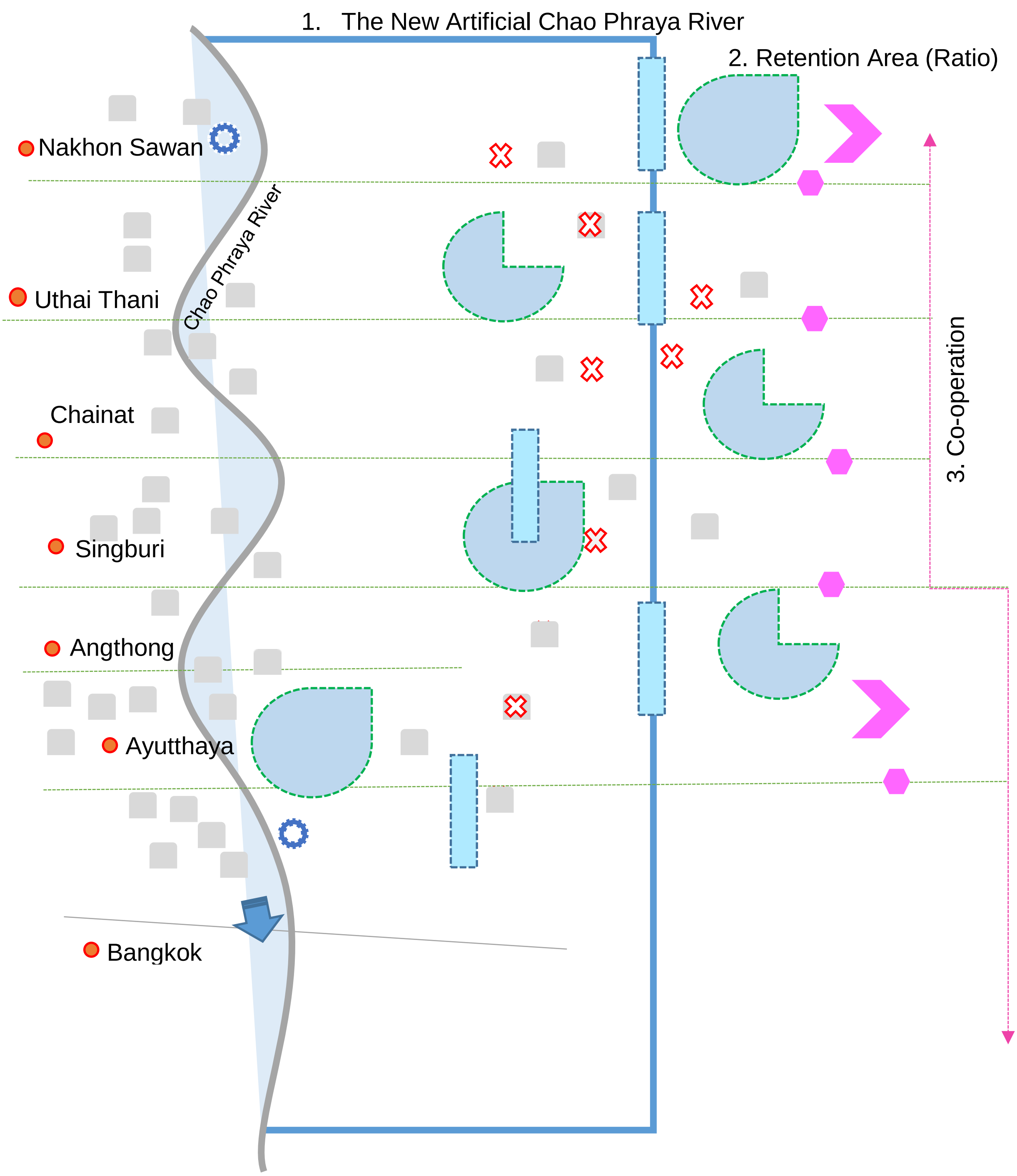


Figure 6.28 Three Main Concept Ideas of flood prevention and adaptation

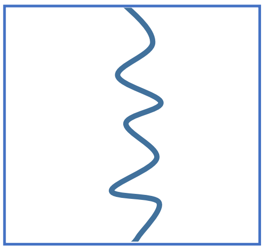
The new artificial river is starting at lower Nakhon Sawan and passes many cities and communities (grey boxes) in the central area of Thailand. Section 1 describes the area until Ayutthaya whereas Section 2 describes the line through the outskirt of Bangkok until the shore line. Furthermore, retention areas should be created together with the new river (light blue bypass) while avoiding housings and forests (cross signs). Beside the structural methods the cooperation between cities (pink line) has to be continuously maintained.

Part 3 Summary: The advantage and disadvantage of a New Artificial Chao Phraya River.

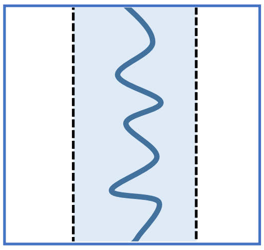
Advantages of a New Artificial Chao Phraya River:
1. The project will reduce and prevent heavy flooding in the central area of Thailand while supporting the main Chao Phraya River as an additional water drainage system. 2. It will create many recreational areas along the new artificial river for activities of the local communities. 3. Some areas along the new artificial river will experience economic advantages by having the ability to organize campaigns or festivals in recreational areas near the river (see also: Danube Festival in Vienna). This can lead to a significant income for the local municipalities and a private income for citizens. 4. The land along the new artificial river will be better organized by land readjustment measures in urban areas and land consolidation in rural areas. 5. The agricultural parts along the new artificial river will better access to fresh water even in dry seasons. 6. The creation of new landscapes will benefit the eco-tourism. New open areas can be used for growing seasonal fruits and native plants of local provenance. 7. The conceptualizing of a new river offers the opportunity to design it with advanced methods and principles. The present Chao Phraya River can be conserved in its present state (natural flow and traditional Thai river lifestyle ; settlement adjacent to river) while the new artificial Chao Phraya River can use new zoning ordinances for the implementation of modern land management concepts (keeping the existing river the way it is and making a new river using present day principles). 8. This research attempted to find a suitable line for the new river. The hydro-calculations considered the topography and the population and forest in areas that the river might pass through. Following these considerations, the new artificial river will have less land relocation impacts by avoiding dense communities. 9. Furthermore, the forest areas will be less impacted due to the fact that the purpose of this research is to create the new artificial river line that is environmental friendly.

Disadvantage of a New Artificial Chao Phraya
1. The project will heavily impact the land owners during the time of the construction of the new artificial river. Even though they will benefit from the project in the future they will be faced with an uncomfortable construction are for a protracted period of time. 2. The government has to purchase the land along the new proposed river line from the owners. This will lead to a high investment for the land expropriation and compensation. There will also be a need for funding for maintenance of the new river that could eventually increase as the line ages. 3. A new river line could separate and change the social interactions of communities by dividing them with the water channel. 4. The excavation land from soil that is gathered from the new artificial river line can be used for building the dykes. However, some soil will be left over which has to be transferred to another place. The excavated land from the project will be deposited in another area which will have a deleterious effect on soil quality in the future.

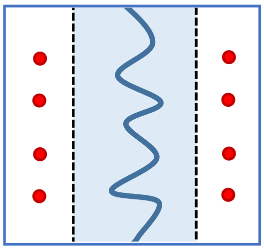
Part 4 Summary: Concept of a New Artificial River and Flood Management



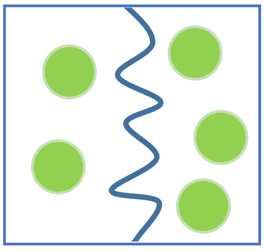
1. Plan and design the new artificial Chao Phraya River for flood protection and adaptation.



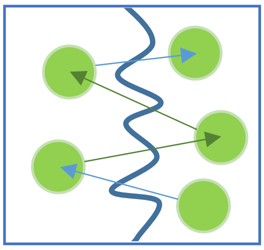
2. Control the flood risk buffer zone along the new artificial Chao Phraya River for flood protection.



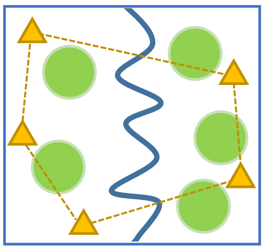
3. Manage the gravity water flow and flood protection in the risk zone area without human settlement.



4. Create water retention and green space areas along the new artificial Chao Phraya River with natural recreation.



5. Connect the new artificial Chao Phraya River with the water retention in flood protection zone areas.



6. Keep a cooperation between communities of the new artificial Chao Phraya River and flood protection in the green open space areas.

Figure 6.29 The concept of a New Artificial Chao Phraya River

7 Conclusions and Outlooks

The following summary is in support of flood risk management through a geodetic approach with prevention and adaptation methods for humankind and natural resources being considered.

7.1 Results of this research

This research is an endeavor to understand one of the most disastrous events in modern Thai history. The massive flooding event that occurred in 2011 caused huge impacts on the country's citizens, economic system and environment. There are many factors that were responsible for the massive losses incurred. However, the two most influential issues were likely climate change (see Chapter 2) and stimulating human activities (see Chapter 3).

Likewise, there has been a review of several case studies in Thailand and selected European countries that have involved with flood disaster on international river cooperation level, flood prevention and adaptation on pilot projects and applied a geodetic approach for flood management. These cases have also used a combination of that approach along with modern land management to lessen the impacts of future flooding-related complications. These methods can be integrated along with proper planning that utilizes high quality mapping information using the latest technology, exchanged experiences, and European methodology. Bringing these technologies and experiences together can be synergistic in supporting research and design to prevent and adapt to flooding disasters in our ever-changing world.

In Thailand, flood problems have been dealt with by using structural methods such as public and private walls, flood diversion channels, and concrete dykes. Non-structural methods, such as land use planning for flood management planning and implementation, unfortunately, have not been worked out for long-term projects (see Chapter3 and Chapter 5). Many existing action plans only applied to small-scale areas as well as short-term projects for flood problem solving. At the same time, some of those solutions may create new residual risks or for other factors that aren't being considered. One instance is the construction of private walls for flood protection which has negatively impacted the concrete embankment and destroyed river-landscape in surrounding areas (see Chapter 3 and Chapter 5).

Understanding European examples (see Chapter 4), especially Austria, Germany and the Netherlands, brings realization of how essential the National River Cooperation in supporting the effort to minimize the impacts from flood problems is to managing flood risk. Netherlands has good examples. One of them is the "Rooms for the River", which is the technique also applied on water retention section of the Rhine River in Cologne, Germany. Other excellent examples can be found along the Elbe River where flood problems are lessened with spatial data in addition to the implementation of relevant laws and regulations between Germany and The Czech Republic. The Danube River in Germany, partly flowing through the Bavarian state, suggests solving flooding for the future with three main action plans, such as techniques, natural water retention, and flood provisional measures. Importantly, a case from Vienna, Austria also presents an interesting example: the new Danube River and the Danube Island, which is designed to enhance the water flow in the Vienna area while splitting the flow capacity of the water. This is achieved while also providing spaces for other activities around the new Danube Island and expanding the green areas along the old and the new river on the adjoining areas. The island has a creative design and functions as a tourist attraction for travelers as well as recreational area for the local population.

This research has been reviewing the disaster protection and flooding experiences of countries in Europe. There is additional focus on flood prevention measures and flood adaptation projects with the use of geodetic approaches and adaptive modern land management. This knowledge and research aims to combine and provide a suitable solution for Thailand and its flood management.

Consequently, this research contends that the most effective solution to reduce the flood risk in the central region of Thailand is to create a new artificial Chao Phraya River. By using new advanced satellite images on German TanDEM-X and TerraSAR-X from DLR and other measures, the new artificial river will create a system of water run off with proper modern land management in urban and rural areas. The river design with cross section purposes to support the material use on soil and natural material even though the run off will be slower than with concrete material, the point is to support construction on balancing environment with harmonized nature. The research has also avoided the impact on land relocation and eco-forest. The process of design attempts to have less community area and natural forest pass though the new Chao Phraya River line. Furthermore, future plans suggest including the implementation of meaningful cooperation between different local authorities on flood forecasting and warning systems while raising public awareness on flood risk and vulnerabilities. There should also be an establishment of community flood policies and plans for long-term optimized flood risk management that are to be followed.

7.2 Flood risk management concepts and techniques

The central region of Thailand is a floodplain (known as the Chao Phraya Basin) where mitigating and adapting to geo-disasters are challenging matters. The design for the new river channel in the low terrain area requires new innovative geodetic approaches with up-to date geo-information. The varying topography of the country brings about various challenges. In the highland areas, there are high slopes where it would be easier to create artificial channels and manage the waterways flowing downwards to the lowland area utilizing gravity flow.

Thus, to design and plan for the new artificial river concept, the following occurrences of the new artificial river are supported by German Earth Observation (DLR) with efficient information on scientific work:

1) The eastern part of the present Chao Phraya River, when analyzed, is considered the most topographically suitable area for extension. The western part of the present Chao Phraya River has a higher topography than the eastern part. Hence, it is more appropriate to support

the new river line in the eastern part of the present Chao Phraya River due to physical geographical circumstances.

Nevertheless, the aerial photographs and geodetic data foundation show the more populous areas are located in the eastern part than in the western part of present Chao Phraya River. This is an important issue that should be highly considered. Importantly, areas in the eastern part where the new river can avoid the old settlements and some dense ecological systems.

By avoiding areas with high concentration of residents and forests there can be a minimization of social problems. These measures in conjunction with environmental diversity and sustainability assessments have to be precisely considered. There will be an increased need to have additional flood protection zones at the locations of settlements. Alternatively, those locations have to be avoided by relocating the communities outside the flood hazard area which can potentially lead to social and financial difficulties to all the stakeholders involved. As a consequence, the flood management should be implemented at the suitable topography and physical conditions to locate the new line of the artificial river and to improve and build new environmental flood zones. The final step is to integrate the technical geodetic approaches with results of multiple outcomes.

Other measures, for steps in the future will support more water retention areas by emphasizing cooperation with the local authorities whom are responsible for the area where the new river is passing through.

2) Due to riverine flooding the central region of Thailand is not only affected by a huge amount of water flow from the northern part, but also by heavy rainfall during the monsoon season. Accordingly, the water retention areas will require highly effective water-saving functionality while natural land conservation is suggested. It can be said that water discharge will be solved by the creation of the new artificial river and the rainfall (precipitation) will be solved by water retention. However, the negative impacts of the natural water retention in tropical countries in an increased concentration of poisonous animals which will create an obstacle in those areas.

Moreover, this research study would like to suggest the calculations of the ratio of water retention and land sharing areas of catchment-scales of each city where the new artificial river will pass through. It is essential to share the land in the same amount of water at each location without the restricted conditions of administrative boundaries.

3) The cooperation between ruling entities of the Rhine River and the Elbe River using joint responsibility of spatial information and local land management on water retention is almost ideal. The approaches when the local authorities are cooperating bring the fastest ways for on-site solutions which will reduce the damage instead of waiting for the national authority to take action. In the case of the cooperation along the new river it will be useful to give the same level of responsibility to well-developed local strategies. Long-term planning benefits are also to be implemented to improve the maintenance in long-term flood management for the future.

4) There will be a need for new regulations along the new river concerning flood protection and plain rehabilitation. This will be suitable for new settlements and relocations and the zoning of safety areas. The usefulness of the law will support the continuous maintenance and improving flood management among the increasing amount of people and the large project such as a new artificial river.

During the process of this research of flood risk management in Thailand by using geodetic approaches various problems in the accuracy of geo-disaster information and available data had to be confronted. Along with the bureaucratic systems and other issues can be challenges.

Thailand has gained an increasing amount of experience in flood-risk management from international cooperation and local experiences. However, in terms of geodetic approaches and modern land management the local knowledge and flood management has not increased to a significant degree, yet.

7.3 The rising challenges of flood risk management

7.3.1 Challenges of climate change and human activities

Flood events are continuously occurring all around the world. Many issues of flooding in the future cannot be avoided due to climate change, urbanization and the rapid growth of the world population.

For those reasons, the challenges of flood risk management can be divided into two main groups.

Firstly, the challenges in climate change and the changing world will be difficult for human beings to control within one country or one bureaucratic boundary. Those climate change issues which are affecting severe flood areas have to be solved in cooperation with the whole world. The cooperation in reducing CO_2 emissions could be one of the methods to help the world's situation getting better from rapidly critical climate changing patterns.

In the case of Thailand, the climate change brings two big impacts – heavy rainfall and the rise of the sea level. Technology can support the weather forecasting in terms of precise rainfall prediction and flood early warning systems. However, another challenge is to raise awareness of local communities which can provide knowledge and management that will be helpful in the future.

Secondly, human activities are also challenging terms of flood risk management. It cannot be denied that the world's population is growing and the expansion of settlements cause destruction of nature and forests and uncontrolled developments in flood prone areas which have been changing the balance of the nature since many decades. In the past, the population living nearby rivers was significantly smaller. Those areas used to be the best places for settlement, agricultural production, water supply, aqua activities, trade and navigation. In the present time, the over-changing of land use patterns makes it more difficult for the flood risk management. The flow of flood water or drainage systems cannot follow the gravitational path from higher to lower areas because of the blockages of many obstacles, buildings, structures, private flood protection walls etc. This results in a harder to solve flood problem which can lead to more severe flooding. Furthermore, it will make it more difficult to implement drainage or flood water canals in human settlement areas. Thus, advanced techniques on geodetic information and data services, such as the Radio Detection and Ranging (RADAR) data, the light detection and ranging (LiDAR) imagery, Airborne laser scanning (ALS) and remote sensing data which supports high-resolution topographic mapping, and measurement technology will support the implementation of flood protection measures. The observation of the earth surface will provide more data and potential information for designing and planning suitable areas along the river and flood-prone communities.

The change of human settlements involves much more challenges for safety measures or the reduction of the loss of life and properties in flood risk situations. Again, geodetic information is essential for the development of measures for heavy flood situation in the future as well as a modern well-organized water and land management.

Finally, climate change and uncontrolled river land use activities, like buildings and facilities activities, located along the river will involve challenges which can be solved with geodetic approaches and modern land management for flood mitigation and adaptation in the future. Many methods which were brought into practice were mentioned before already. Some of them are suitable for specific countries and some methods can be adjusted for the conditions in different flood risk areas.

7.3.2 Improved alternative flood management with benefits for the long run

When trying to resolve above challenges, we have to accept that one single method cannot solve all flood problems. This research suggests creating a new artificial river as the main solution. It is expected that the new concept will be suitable for the central area of Thailand. The new location will provide a new strategy for advanced tools of technology, raising local awareness, law & regulation for land management of flood risk area and mitigation and adaptation.

Since the flood occurred in 2011 in Thailand, the government has been using multiple choices of strategies, technologies, designs and plans to apply on the flood prone areas in central Thailand. The combination of structural and non- structural measures is required to reduce the damage of floods in the future. It is considered to invest a higher budget on structural defenses than on non-structural measures. However, the non-structural measures are expected to be the ultimate goal of a more sustainable flood management planning.

The structural flood defense method may be suitable for areas with dense population areas; however, flood control structures have a limited time and performance.

The structural flood control can also create “a ‘moral hazard’, misleading a vulnerable community from a true appreciation of the risks associated with occupying the floodplain” (McBain, 2012). Therefore, the ratio of structural and non-structural measures should be balanced between urban and rural areas. Retaining this ratio in balance will be a challenging measure in the future.

This research supports that the non-structural measures can be combined with the structural methods in the sensitive flood prone areas by using land management in terms of land use planning and zoning ordinance. The historical local settlements are providing good methods for flood adaptation, e.g. floating houses, raised buildings (Thai traditional houses), integrated local material for flood resistant constructions for facilities. Those methods should be applied on local communities nowadays to gain benefits on flood adaptation in the long term.

Underpinning this research, a new artificial Chao Phraya river is one option which is aiming to minimize the flood risk in the future. This artificial river cannot solve all flood problems; furthermore, the new river has to be combined with other flood adaptive management methods. The research expects that the concepts will be beneficial for national responsibilities and local communities.

Thailand should begin from setting up a genuine water framework and establishing an essential flood policy and legislation for promoting a design and a plan for the scale of the river for flood adaptation. The optimized geodetic information on advance technology should be available for flood management on national and local scales. Also, data access in flood hazard zones should be easily accessible for local communities which will ensure minimized the risk of floods in the future. To create appropriate modern land management with emphasis on land use planning, a life in harmony with the water along the river and the environmental atmosphere, Thailand has to confront with the flood challenges in a changing world.

7.4 Conclusion on Flood Management

Flood management is an increasingly crucial issue for Thailand. The two issues of human activities and climate change mainly cause flooding. Combining the methods of geodesy, hydrology, meteorology, remote sensing and topographic mapping will support the physical planning of flood management measures. Furthermore the building code, environmental impact assignments, agricultural ecosystems, the recreation of landscape and economic benefits will improve the social aspects in that area, for example, providing room for the river and well-structure the flood prone area, having set back settlements and zoning the use of land at the nearby river while providing equal weight to the environment and the development for the future.

All in all, climate change and human activities create much more extreme situations even though nowadays there is a common awareness and realization in the population and communities of the human behavior and the climate change. The extreme situations due to the climate change lead to more flooding, and furthermore the enormous flood protection measures created by humankind will have even more impacts on some local community in some ways. Therefore, the investment in the new artificial Chao Phraya River will be more valuable for the future. Having an environmental friendly concept of flood prevention and adaptation, creating more recreation areas and providing more open space and wider areas of nature for local communities will be the best solution. The important cooperation of surveyors, city planners, water managers and land managers will make the flood management projects work in the long run.

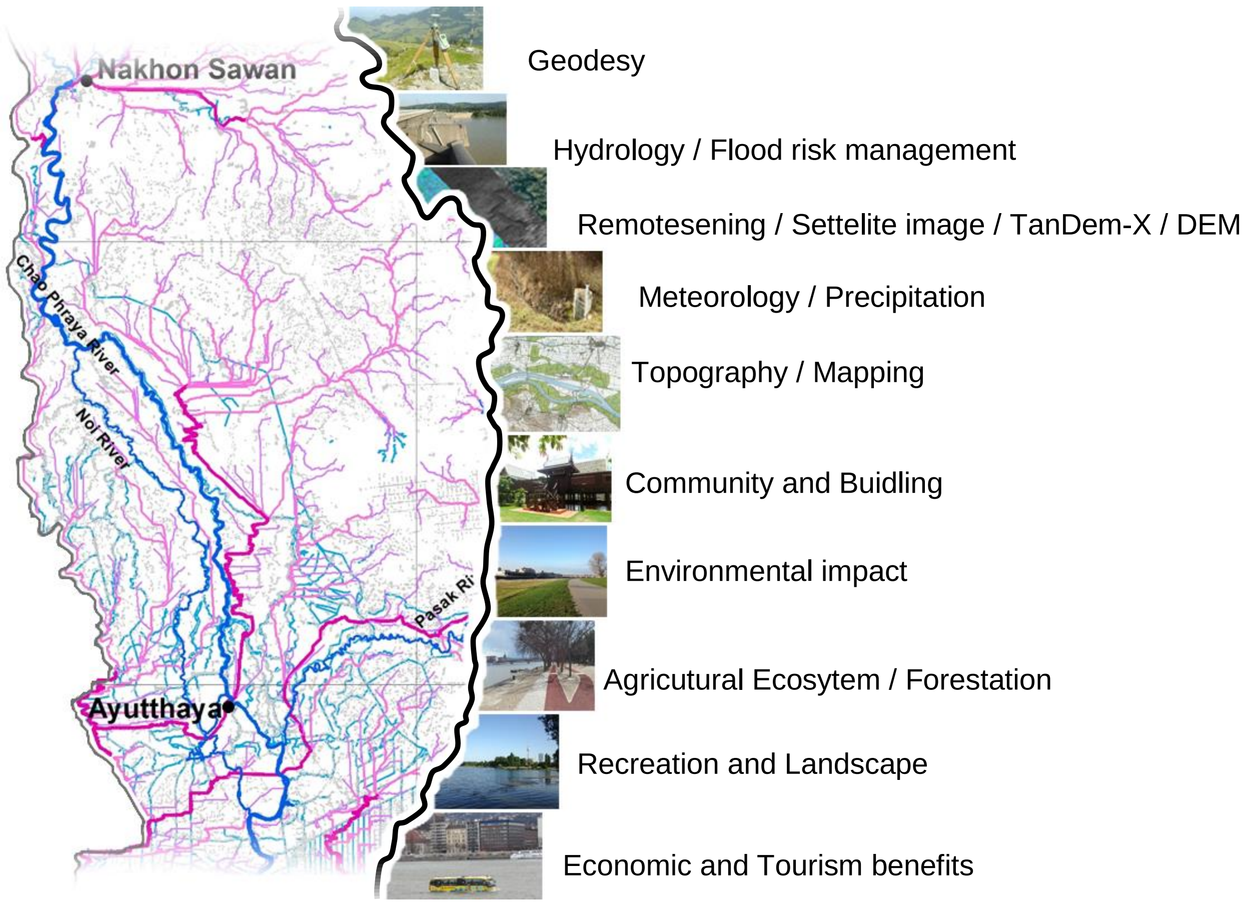


Figure 7.1 Geodetic Approaches with other benefits of the New Artificial Chao Phraya River

7.5 Outlook

The outlook will provide suggestions for an enhanced new artificial Chao Phraya River concept and a balanced retention area in cities where the new artificial river will pass through. To make it a sufficient future project, the government should have measures for developing and conserving flood prevention and adaptation in the future occurring due to severe climate changing issues.

Geodetic technology will provide sound information which will support the planning and designing for well-appropriated allocation of land and water management. The new artificial river area will support the flood reduction. The neighborhood area nearby will gain benefits in terms of recreation areas, plenary ecosystems and a harmonized environment for the local and the national Thai communities.

This research has three main suggestions, such as a new artificial River, a balanced retention area and integral all-level cooperation. Those three suggestions will only be completely useful when there are future tasks added as described below.

7.5.1 Future works

The Future works will improve the new artificial river concept. The Geodetic approaches are challenging and valuable methods for supporting the climate change adaptation in Thailand.

To develop the new artificial Chao Phraya River, the responsible organization should concern the measure to reduce the future flood risk in the central region of Thailand.

The efficient works for the future which are suggested by this research are listed below:

1) In terms of economic investments on the construction, “costs and benefits” should be considered in detail. The mega-project of the new artificial Chao Phraya River will be more sufficient for long-term periods and it is expected to minimize the massive flood impacts in the future.

2) Concerning the environmental management issues, the next research can also study on the Environmental Impact Assessments (EIA). It is hard to deny that most constructional projects will have an impact on the environment. However, creating a new ecosystem can be a solution for the destruction of large natural areas during the construction process. The newly built human-made nature will compensate those construction sites. Thus, the EIA and the compensated forest community will provide interesting topics for future researches. In addition, the forest communities in the flood zoning area will make more benefits for the natural ecosystem and is supporting the solutions for climate change adaptations.

3) Regarding social issues, Social Impacts Assessments (SIA) is one more important measure for an implementation of the suggestion of this research, if the SIA are able to weight and balance between positive and negative intentions. So In the future, with the new artificial Chao Phraya River there will be benefits for the social public areas. Those areas can be used as sport tracks or bicycle routes. Therefore, the research area will become interesting for a wide spectrum of people.

On the other side, the open space area will easily lead to some problems, because in tropical weather conditions those areas will be suitable for homeless people, illegal drug trade, poisonous animals, etc. These topics will challenge the research on the measures to control and manage the public space.

4) Technical support will be useful in the future for the flood management. The geodetic approach still has more challenges to research on, e.g. works on floods along the river, landslides, blockages and debris flows from the facilities constructions. Advanced surveying and mapping will bring more accuracy to the collected data and analyzing it will support short term plans of early warning systems, evacuations and long-term plans (new measures for flood protection and adaptation).

5) To cooperate on the climate change, a lot of issues still have to be researched and supported on the way to efficient flood disaster management. Top-down policy and bottom-up practices, spreading of knowledge and practitioner on the cooperation will make the projects less abstract, more substantial and successful in the management of flooding issues.

6) Other disaster issues such as drought can also be solved by functions of the new artificial river and the retention areas. There will be more benefits during the dry seasons when there is not much water for the community's consumption. Those projects will relieve drought hazard where drought impacts and loss of economic have been occurring in the past already.

To sum up, based on a generalized knowledge the usage of geodetic technologies will be the best method for choosing the best location for a new artificial Chao Phraya River and suitable locations for retention areas.

The sound information as a precise, high resolution and accuracy data of surveying and mapping will support the best decision making for planners to design and plan on the relevance water and land management to the multi-useful function of flood protection and adaptation not only in Thailand but also in the changing world of the future.

7.5.2 Vision

Moving towards the next vision of the new artificial Chao Phraya River concerning the "Sustainable development of flood adaption projects".

The need for the quality crate the riverscape will be working together with social, economic and also ecological factors. Attractive for landscape will stabilizing and identifying factor in the planning process. The development landscape will develop urban and rural of outstanding merit (Hölzer et al, 2008)

This research totally promotes the human creation of the new artificial Chao Phraya River. Because of the benefits of the project it will not only reduce the flood disasters, but also have other environmental advantages. In the same time, apart from the quality of environmental and ecological factors, the riverscape will lead to the start of a lot of other projects which will enhance the social benefits and economic activities. Those activities will take place in priorities respectively.

Therefore, the good combination of geodetic approaches, the river design, land management, environmental activities and networks will make the new river project more multi-function. This research will suggest the following seven visions:

- **The policy of flood management**

The policy is one crucial issue because the roles and responsibilities are not clearly given. A major problem is that the hierarchical levels of the responsible departments are equal. Therefore, the departments cannot order other authorities to follow long term plans, hence, a close cooperation between those is needed and a new main authority has to be set up. The new artificial Chao Phraya River will be one mega-project which will consume a lot of investment. The benefits of the project will ultimately appear in the long run for the Thai nation.

- **Providing adequate geo-data resources**

The accurate information on surveying and mapping will become more essential on integration in planning and design of flood disaster management. Also, weather forecasting requires a new up-to-date information system with high accuracy. Firstly, the government unit who is responsible for this work should provide reliable information. Secondly, data sharing between departments or with the research section should be in practice. Therefore, the result of the flood disaster works will be provided by cooperation and exchange of a greater variety of sharing knowledge. These results will be more effective for solving the mentioned flood issues.

- **Planning on a regional level**

The central government should begin to work progress on the regional planning. The regional planning will suggest/control the location of settlements and activities along the river. Especially, a drastic change of the human settlement patterns along the river will relevance with the complement policy and facilitating actions. The land use control for the area of the new artificial river and the water retention area should be designed as a law for the community with a bottom-up approach. This is one opportunity for the local government to learn about flood adaptation concerning anthropogenic inventions and climate change issues.

- **Raise awareness of the social community**

In terms of the awareness, the understanding of the complexity of flood risks, learning to live with flooding and benefits of the long-term project have to be spread. Urban areas can solve the flood problems by combing the structural and non-structural methods, while rural areas need to keep the benefits of the non-structural methods. This result will make the community a better place for living.

- **Community knowledge management**

The community should begin to learn how to record the level of the flood water and the impacts of flood events. The data collection of the flood statistics was not recorded frequently and was not transferred into the mapping in the past. When the data is available and we have a clear image of the flood protection and adaptation of the community that will show the flood details easily in the future. Having basic knowledge of the record and the collection of the flood data will make it more convenient to plan and make decisions to solve the flood problems for the communities on time.

- **Technical knowledge and financial support for the flood adaptation**

The technical knowledge support and the financial support can come from public as well as private or even international cooperation. In the past, mostly the public was providing the budgets for the post-disasters of flooding. However, pre-disaster and in between the disaster periods there has to be a technical knowledge and budget support as well. Therefore, the construction process of the mega-project new artificial Chao Phraya River and the balancing of the retention areas have to have well-allocated budgets for completion of the project. Hence it is suggested to divide the stages of the project in phase I (the construction as human-made nature) and phase II (the maintaining stage) whereas both phases are provided with continuing subsidies. This process will make the project keep running for a long-term period.

- **Perspective with smart vision on flood disaster as sustainable development opportunity**

Addressing flood and other disasters will become more challenging in the near future due to climate change issues. The opportunities, the mitigation and the adaptation have to improve and adjust to new generations. Our ancestors learned how to survive with adaptation in the past, whilst our present generation has to learn how to create alternatives to survive disasters and still live in harmony with the environmental system. The creation of new measures like the new artificial river is a contemporary challenge. Our generation will leave a valuable solution for legacy during heavy rainfall, a high rising sea level, extreme changing of the climate and massive influences of anthropogenic issue. The next generation will learn more from the past and adjust better for the future, hopefully!

In summary, the point is to create a new river as an alternative solution for a better living under flood conditions of our generation. Using a contemporized advanced technology combined with the already gained knowledge will result in making a better place for living with flood adaptation.

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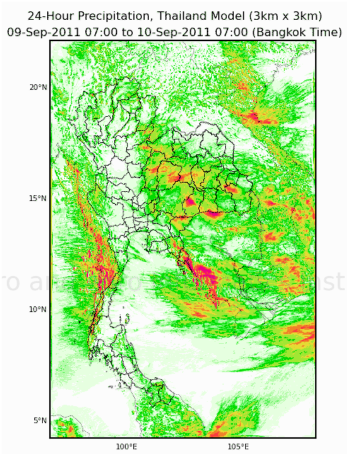
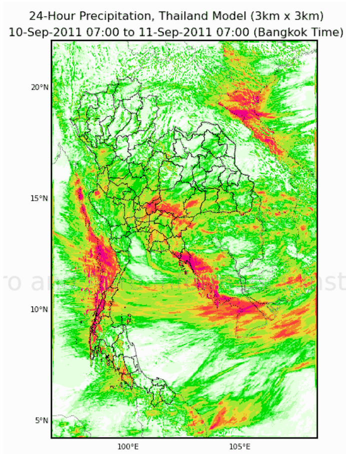
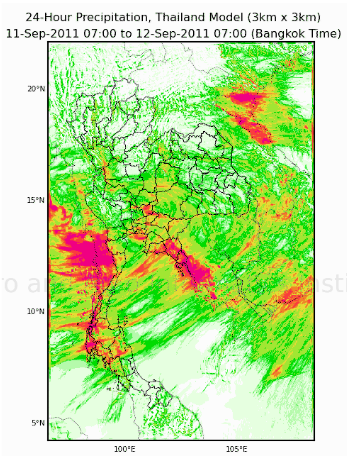
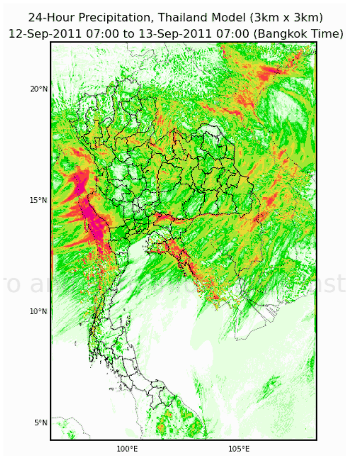
Appendix

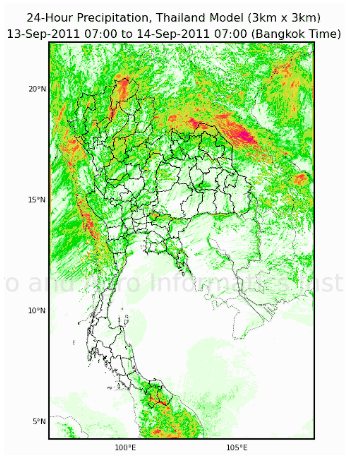
Appendix 1: Record flood events after a tropical cyclone in 2011



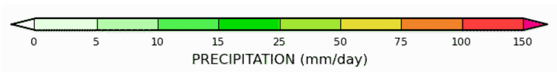






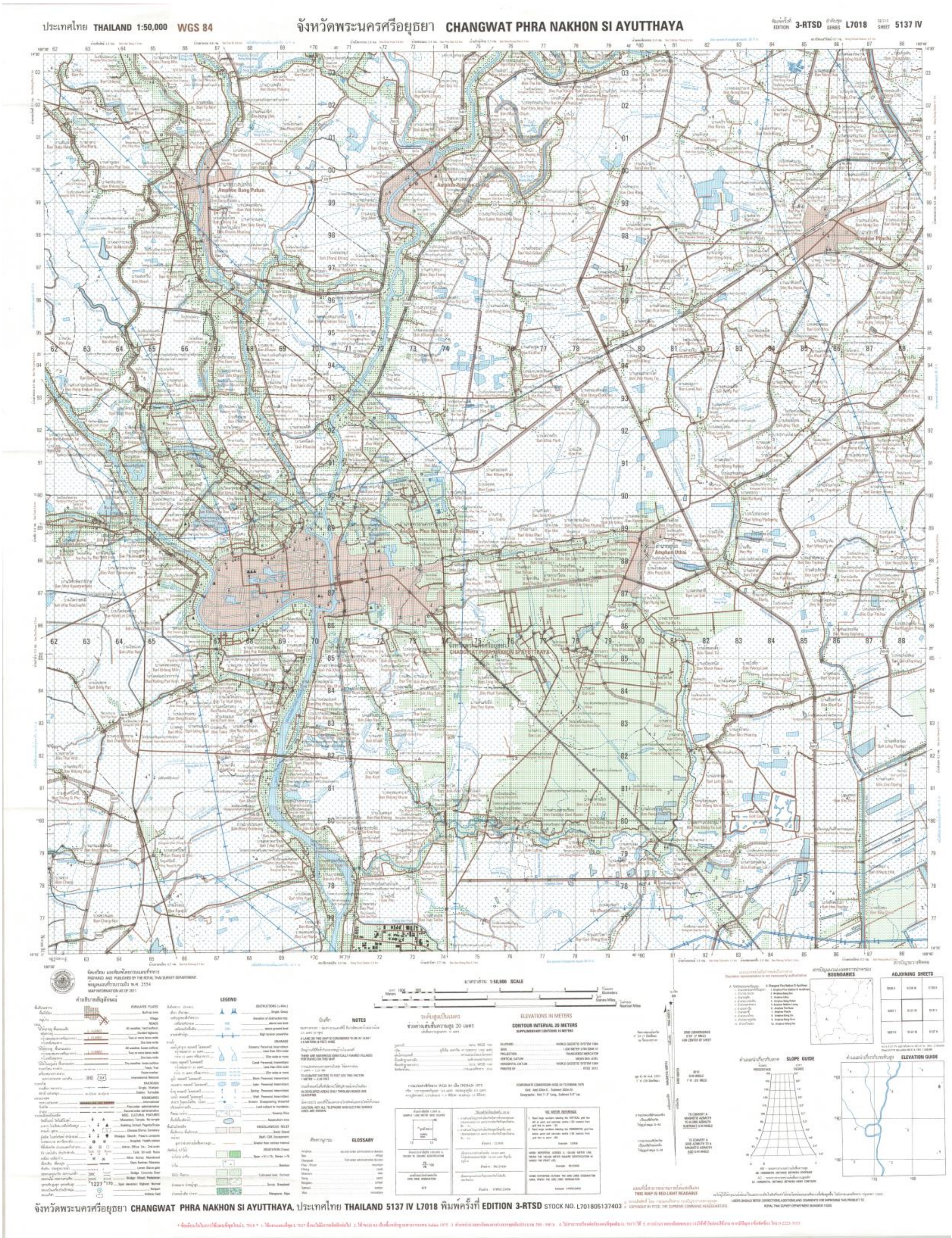


The tropical cyclone hit the central area of Thailand from 09. to 13. September 2011



Hydro and Agro Informatics Institute, Thailand
https://www.haii.or.th/

Appendix 2: Topography map of Ayutthaya from RTSD



Appendix 3: TanDEM-X Mission

The scientific applications can be summarized in three groups. The following section is completely referred from DLR, 2016b.

1) Across-Track Interferometry

A consistent and reliable DEM data set with global coverage and DTED-3 standard is an important information for a variety of on-going research areas and will allow new scientific applications to be developed.

Examples are:

- hydrology (ice and snow, wetlands, morphology and flooding),
- geology (geological mapping, tectonics, volcanoes and land-slides),
- land environment (cartography, urban areas, disaster and crisis management, navigation, archaeology and change detection),
- renewable resources (land use mapping, agriculture, forestry and grassland),
- oceanography (wind and waves, ocean dynamics, sea-ice, ship detection, oil slicks and bathymetry). Some of these applications foresee the combined use of along- and across-track interferometry as well as polarimetry to enhance current products.

2) Along-Track Interferometry

Along-track interferometry will allow innovative applications to be explored. Along-track interferometry can be performed by the so-called dual-receive antenna mode (ca. 2.4 m along-track baseline) and/or by adjusting the along-track distance between TSX-1 and TanDEM-X to the desired value (up to 4 phase centers). By means of newly developed orbit concepts, the along-track component can be adjusted from 0 to several kilometers. The combination of the two different along-track baselines will be explored for moving target detection (MTI) and traffic monitoring applications. The following sub-groups have been defined for along-track interferometry:

- Oceanography (Ocean currents maps, ocean wave spectra),
- Moving Target Detection (Traffic flow monitoring maps - see also moving target techniques in application area C),
- Glaciology (Ice flow monitoring maps).

3) New Techniques with Bi-Static SAR

The TanDEM-X mission will provide the remote sensing scientific community with a unique data set to exploit the capability of the new bi-static radar techniques and to apply these innovative techniques for enhanced parameter retrieval:

- Super Resolution (high resolution maps, micro-topography enhancement maps, feature extraction algorithms)
- Bi-static SAR (new bi-static SAR processing algorithm s, multi-angle SAR, enhanced scene feature extraction, combination of mono-static and bi-static signatures),
- Moving Target Detection (detection of ground moving targets and the estimation of their velocity using digital beamforming and STAP techniques with the 2 + 2 phase centers of the TerraSAR-X and TanDEM-X antennas),
- Polarimetric SAR Interferometry (DEM optimization using polarization diversity, vegetation bias and structure maps, crop biomass).

Appendix 4: Generating river network using DEM data

In this description, specific file names were used. Hence, the names displayed in bold can be changed for other projects.

1. Add the DEM File with the Button “Add Data” (**Thai.tif**)
2. In the Toolbox go to:
   Spatial Analyst Tools → Hydrology → Fill
   a. Select as “Input surface raster” the **Thai.tif**
   b. Give the “Output surface raster” the name **Thai_Fill**
   c. Click “OK”

   A new Layer is created with the name **Thai_Fill**
3. In the Toolbox go to:
   Spatial Analyst Tools → Hydrology → Flow Direction
   a. Select as “Input surface raster” the **Thai_Fill**
   b. Give the “Output surface raster” the name **Thai_FlowDirection**
   c. Click “OK”

   A new Layer is created with the name **Thai_FlowDirection**
4. In the Toolbox go to:
   Spatial Analyst Tools → Hydrology → Flow Accumulation
   a. Select as “Input surface raster” the **Thai_FlowDirection**
   b. Give the “Output surface raster” the name **Thai_FlowAccumulation**
   c. Click “OK”

   A new Layer is created with the name **Thai_FlowAccumulation**
5. In the Toolbox go to:
   Spatial Analyst Tools → Map Algebra → Raster Calculator
   a. Double-click as “Map Algebra expression” the **Thai_FlowAccumulation**
   b. Add the equation: > 3000 so that in the “Map Algebra expression” field the following is displayed:
      “Thai_FlowAccumulation” > 3000
   c. Give the “Output raster” the name **Thai_SingleOutput**
   d. Select as “Output data type”: FLOAT
   e. Click “OK”

   A new Layer is created with the name **Thai_SingleOutput**
6. In the Toolbox go to:
   Spatial Analyst Tools → Hydrology → Stream Order
   a. Select as “Input stream raster” the **Thai_SingleOutput**
   b. Select as “Input flow direction raster” the **Thai_FlowDirection**
   c. Give the “Output surface raster” the name **Thai_StreamOrder**
   d. Select as “Method of stream ordering” the STRAHLER Method
   e. Click “OK”

   A new Layer is created with the name **Thai_StreamOrder**
   This Layer now shows three Sub-Layers with different colors, which can be adjusted in the Layer Properties. The Sub-Layer with the number 1 is referring to the smallest rivers, whereas the Sub-Layer with the number 3 is showing the biggest water streams.
7. In the Toolbox go to:
   Spatial Analyst Tools → Hydrology → Stream to Feature
   a. Select as “Input stream raster” the **Thai_StreamOrder**
   b. Select as “Input flow direction raster” the **Thai_FlowDirection**

c. Give the “Output surface raster” the name **Thai_StreamToFeature**
d. Click “OK”

A new Layer is created with the name **Thai_StreamToFeature**

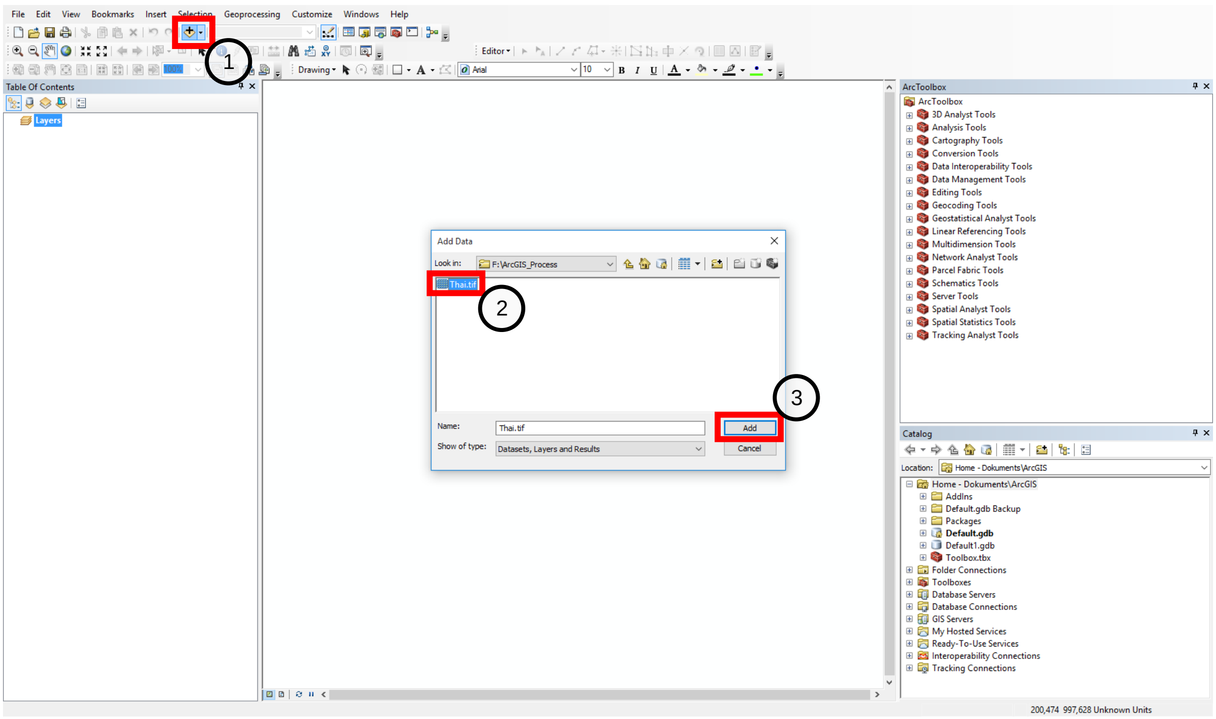
This Shapefile now shows the different water streams in differently sized lines, which can be customized under:

Properties → Quantities → Graduated symbols

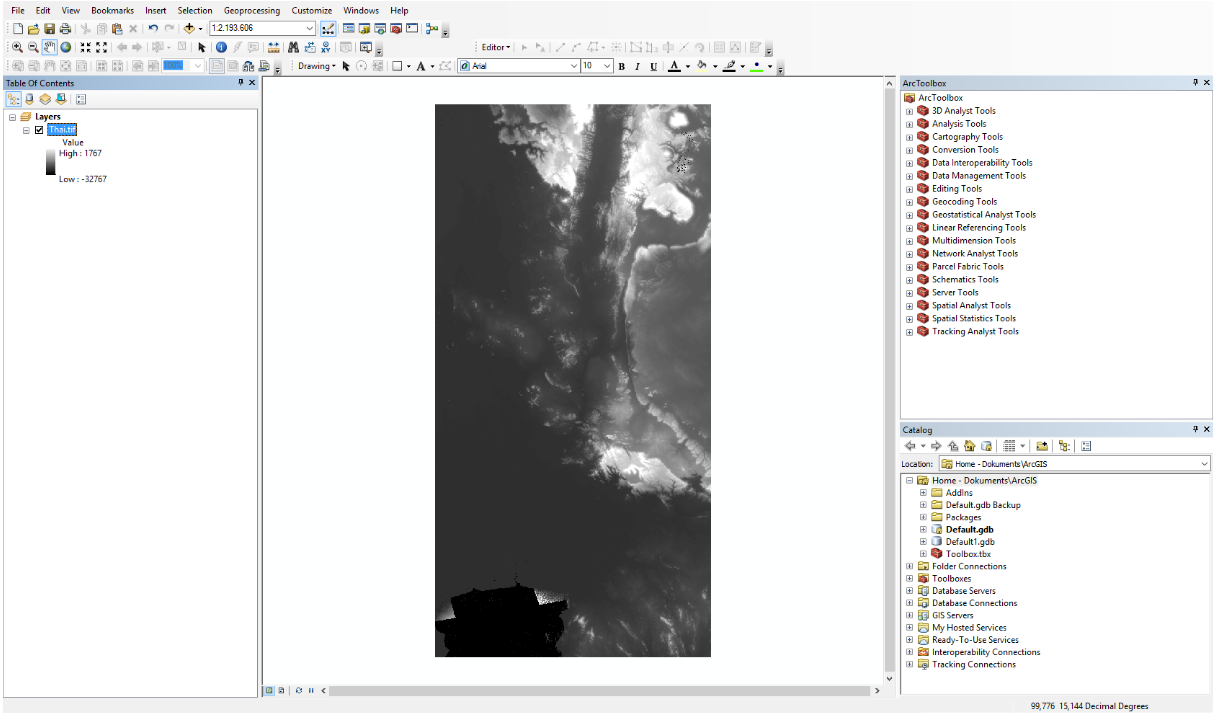
e. Select as “Value” the GRID_CODE
f. Color and size of the lines can be adjusted

Steps:

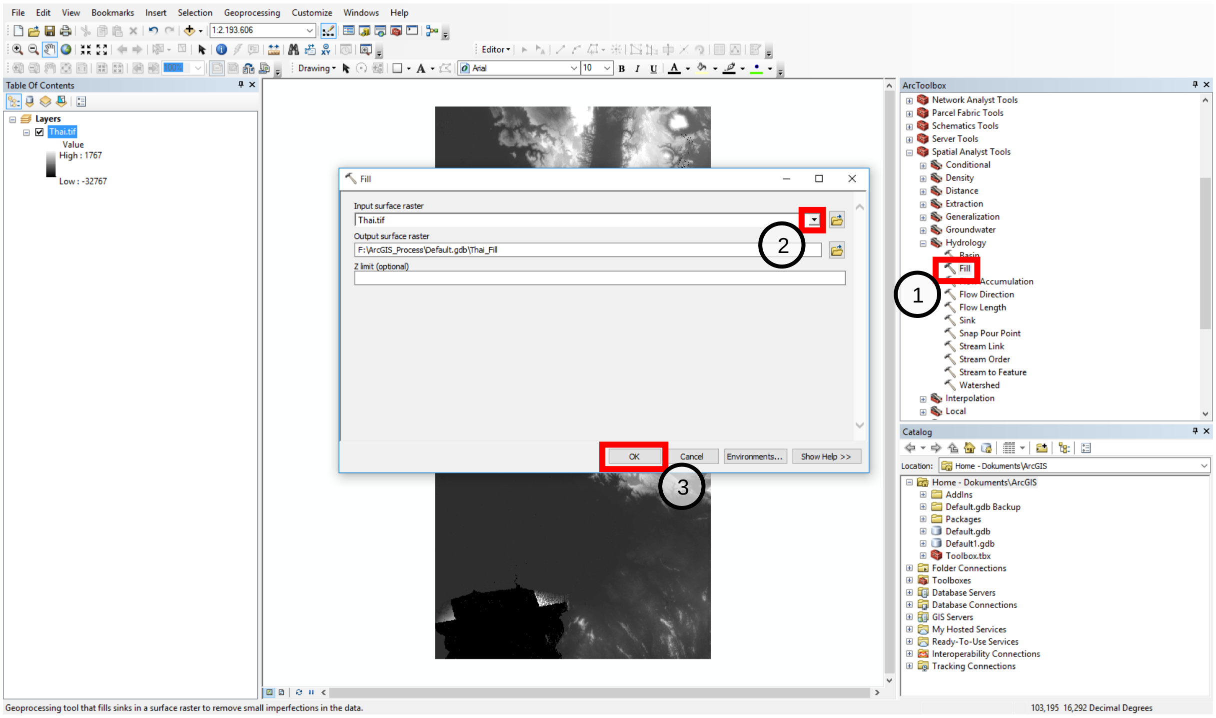
1.1. Adding the Thai-tif File as a Layer



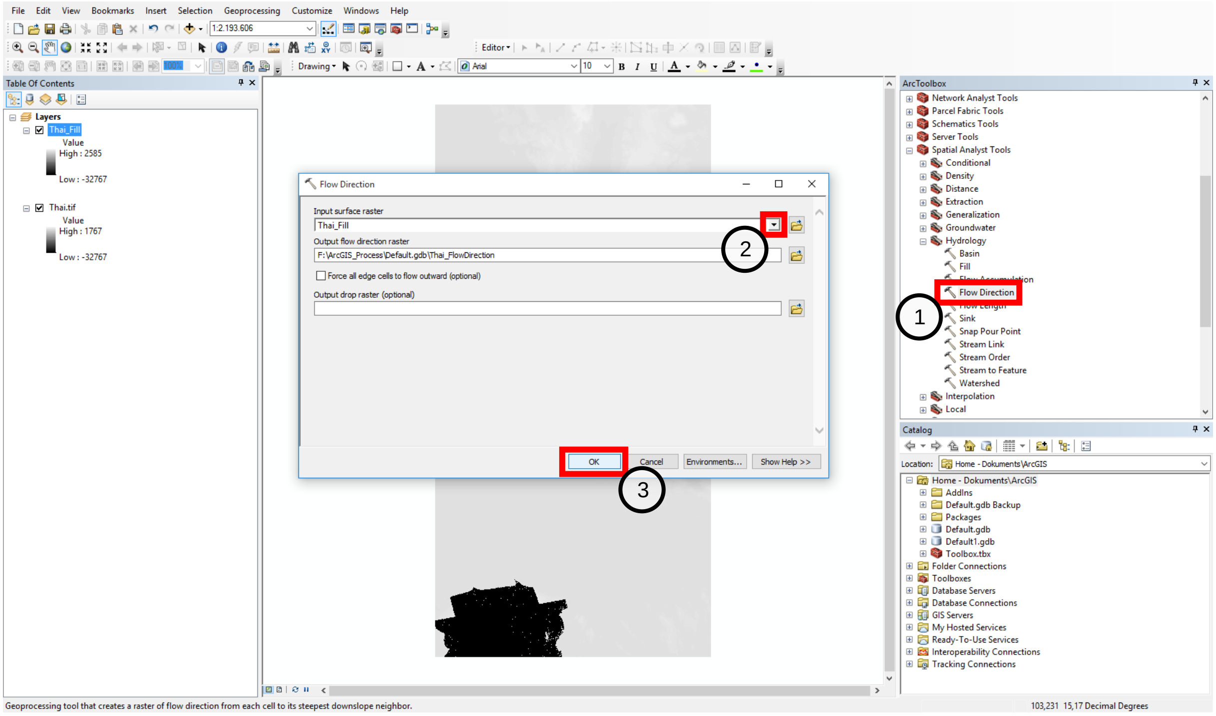
1.2. Display of the Thai.tif DEM data in ArcMap



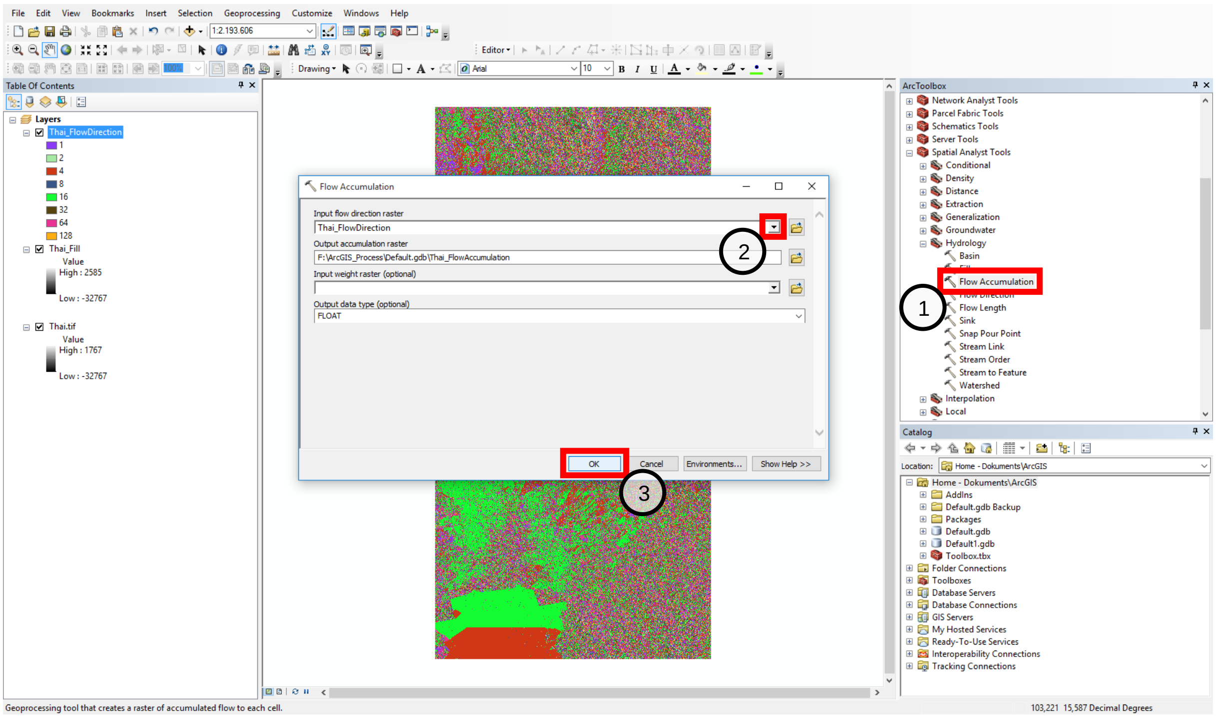
2. “Fill”-Operation applied to the Thai.tif Layer



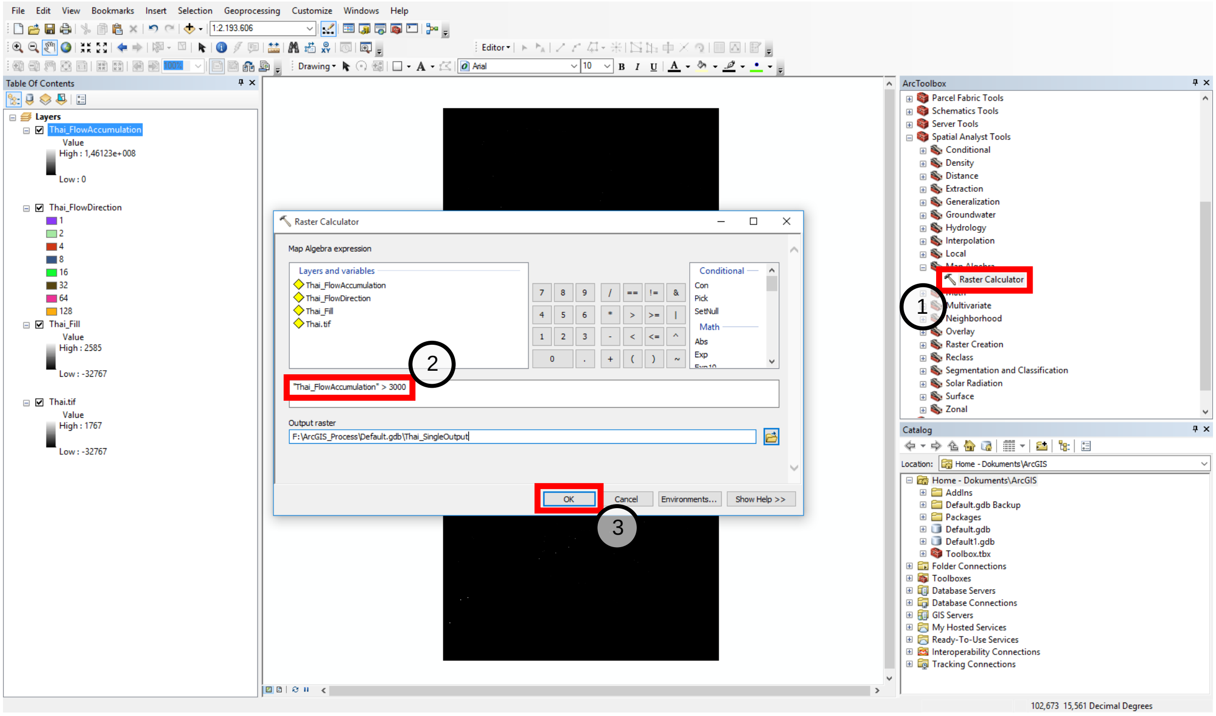
3. “Flow Direction”-Operation applied to the Thai_Fill Layer



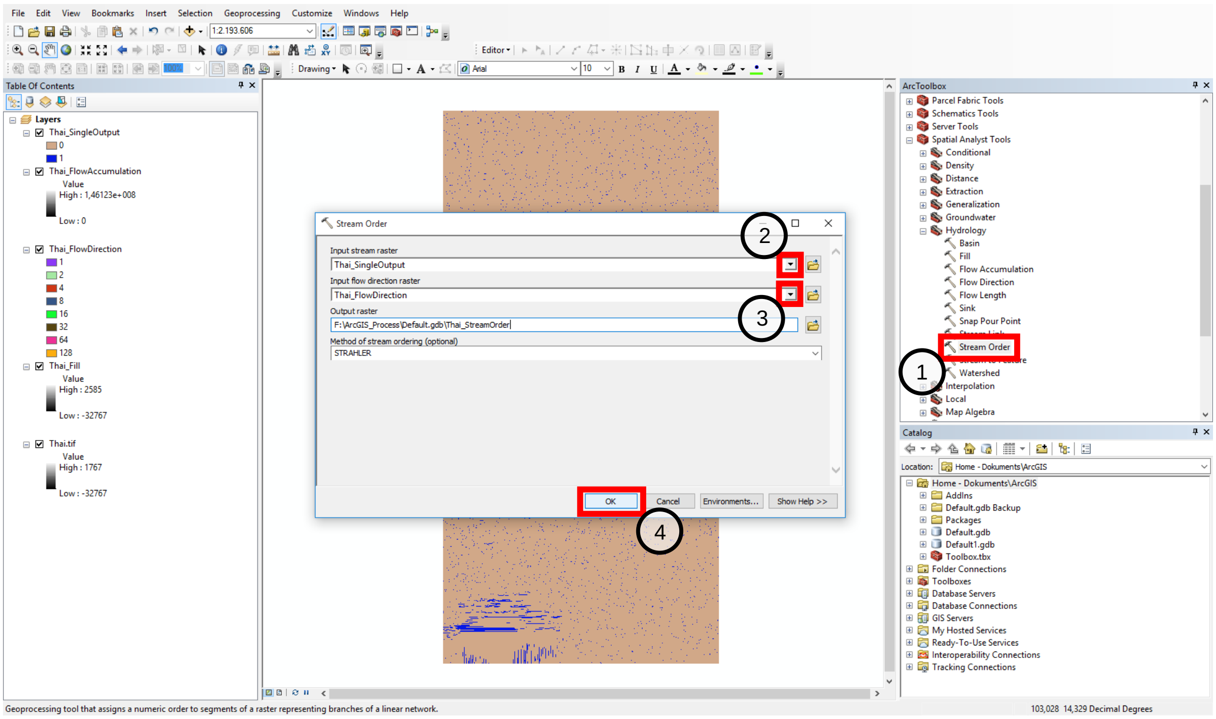
4. “Flow Accumulation”-Operation applied to the Thai_FlowDirection Layer



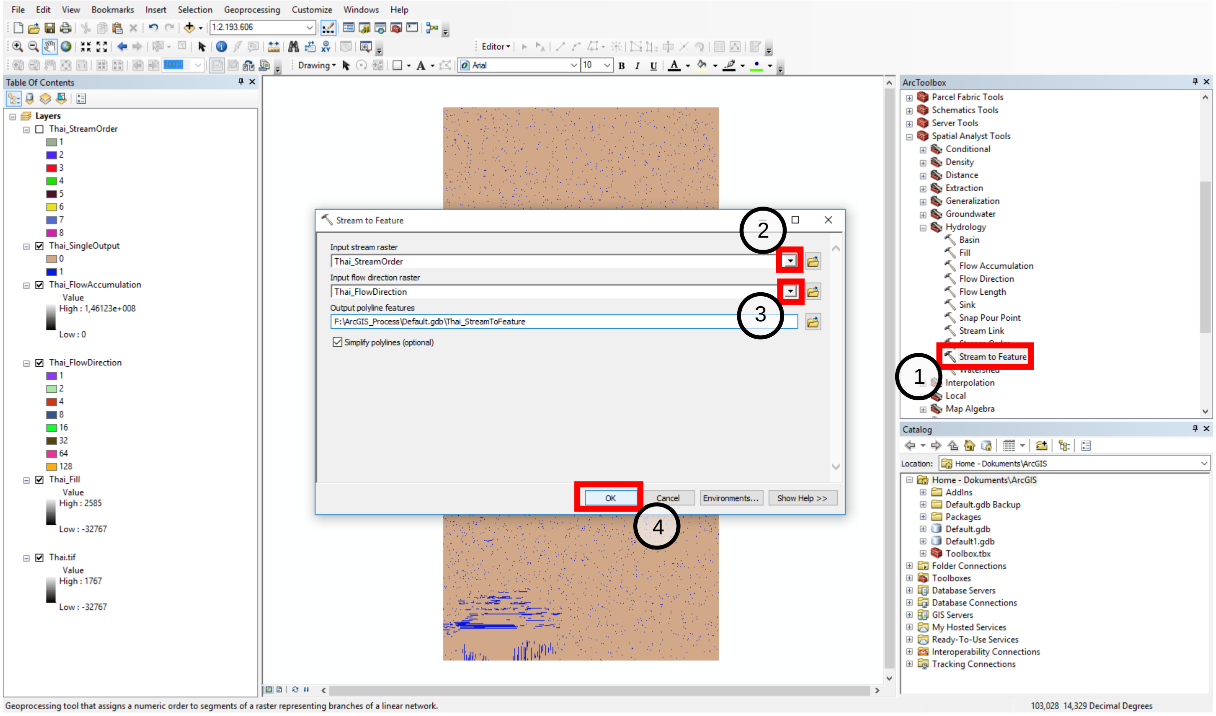
5. “Raster Calculator”-Operation applied to the Thai_Accumulation Layer



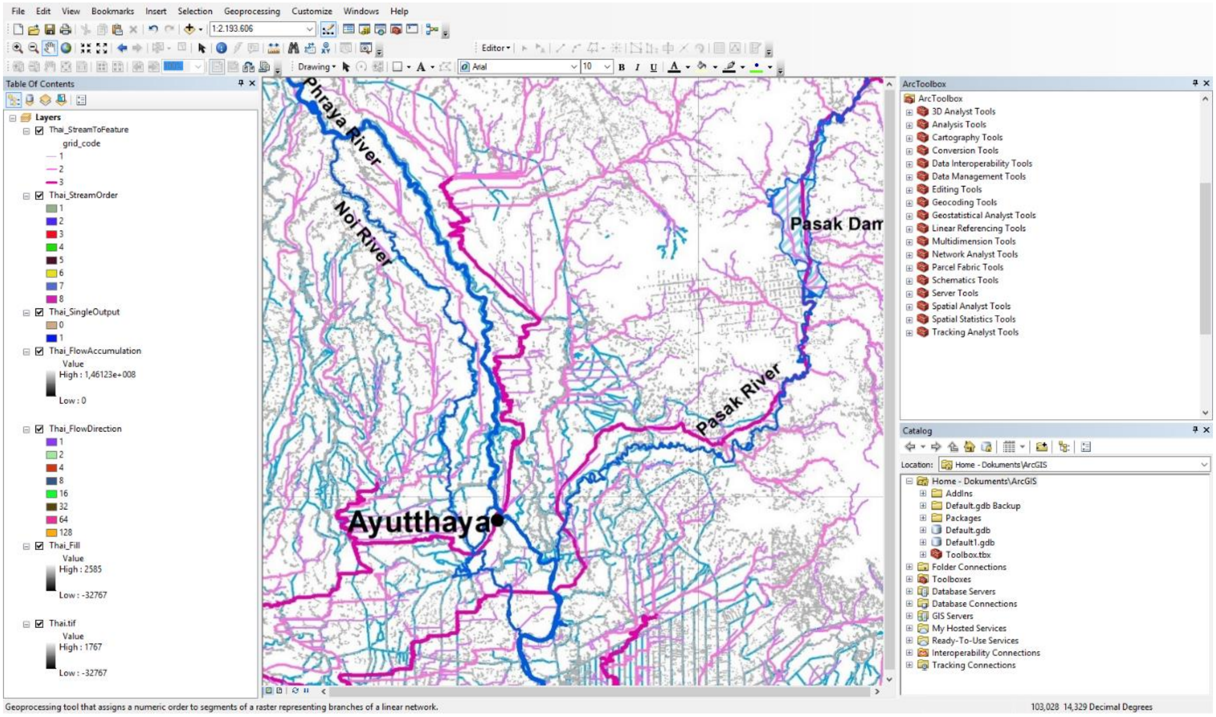
6. “Stream Order”-Operation applied to the Thai_SingleOutput Layer



7.1. "Stream to Feature"-Operation on the Thai_StreamOrder Layer



7.2. Display of the finished Map with the calculated river lines in three shades of pink



Appendix 5: River cross section calculation

Channel Section

Specification:

- Q Flow rate [m^3/s]
- I_o Channel / River bed slope [m/m]
- z Height relative to the reference level [m]

Cross section:

- **Compact channel with shallow water area**

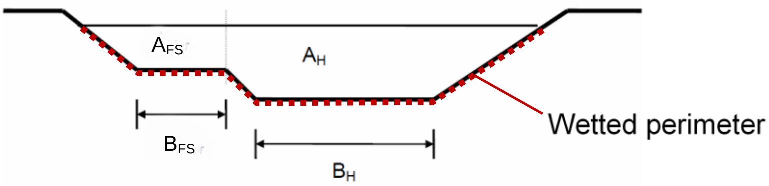
In a flood situation the depth of the water in the floodplain area is high and therefore the velocity of the water stream in the shallow water area is the same as in the area of the main channel. (LfU, 2002)

According to Kradolfer (1983) it is accepted to do the calculations without separating between the flood plain area and the area of the main channel (compact channel) when the following conditions are compiled:

$R_{FS} > \frac{R_H}{2}$ and $B_{FS} \leq \frac{B_H}{2}$

with $R = \frac{A}{P}$ Hydraulic radius

and P Wetted perimeter



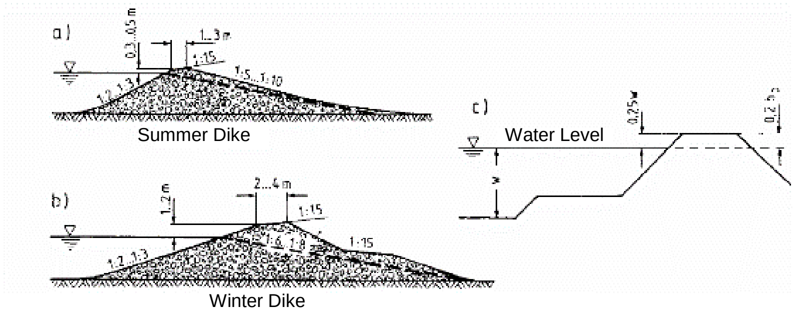
B_{FS} or B_H resp. Width of the floodplain or the ground of the main channel resp.

A_{FS} or A_H resp. Cross section area of the floodplain or the main channel resp.

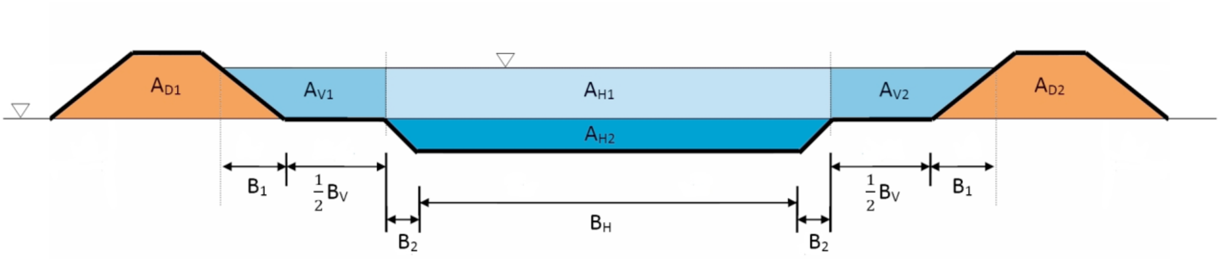
Dyke:

- **River dyke (flood protection dyke)**

Cross section as described by Lange/Lecher (1989)



Calculation of the geometry of the cross section



$A_H = A_{H1} + A_{H2}$ Cross section area of the main channel

$A_V = A_{V1} + A_{V2}$ Cross section area of the flood plain

$A_D = A_{D1} + A_{D2}$ Cross section area of the dykes

B_{DK} Width of the embankment top (dyke top)

B_H Width of the main channel

B_V Width of the floodplain area (left and right side added)

h_H Depth of the water in the main channel

h_V Depth of the water in the floodplain area

$h_{H2} = h_H - h_V$ Depth of the main channel relative to the floodplain area

m Slope of the dyke

m_H Slope of the main channel

$B_1 = m\, h_V$

$B_2 = m_H\, h_{H2}$

f_D Dyke freeboard

$P_H = 2\sqrt{m_H^2 + 1}\, h_{H2} + B_H$ Wetted perimeter of the main channel

$P_V = 2\sqrt{m^2 + 1}\, h_V + B_V$ Wetted perimeter of the floodplain area

Geometric specifications

1. Dyke top and und embankment slope

   The paper „Flussdeiche Überwachung und Verteidigung" from the Baden-Wuerttemberg Institute for environment protection LfU (2005) recommends a width of the dyke top of at least 3.0 m and a slope of the embankment with a ratio of more than 1:2.

   ⇒ B_{DK} = 4.0 m und m = 3 (embankment slope ratio 1:3)

2. Dyke freeboard

   According to Haselsteiner/Strobel (2006) the freeboard of the dyke should be minimum 0.5 m. High wind build-up, waves and water streams can make higher freeboards necessary. In Germany dykes of the class DK-III (higher than 5.0 m) are required to have a freeboard of at least 1.0 m. (BLfU, 2009)

   ⇒ f_D = 1,0 m

3. Complying the conditions for the calculation as an compact channel

   As mentioned before, it is accepted to consider the cross section as a compact channel for the calculations according to Kradolfer (1983). Therefore, the following conditions have to be compiled:

   - The channel bed roughness of the main channel and the floodplain area have to be similar.

   - The width of the floodplain area should not be wider than half of the width of the main channel:

     $$2\ B_{Vor} \leq B_H$$

   - The depth of the water in the floodplain area should not be smaller than half of the depth of the water in the main channel:

     $$2\ h_V > h_H$$

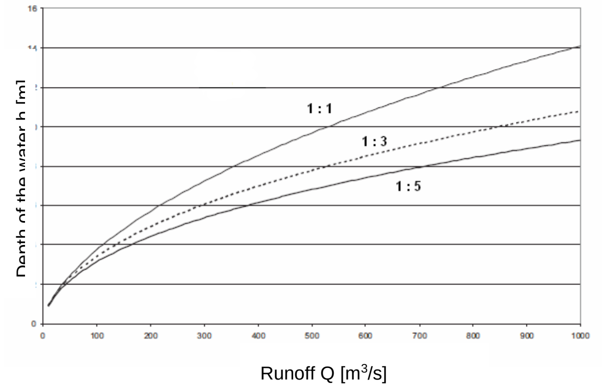
4. Equalized mass-balance

   A compact channel with foreshore area has two benefits. First, the dykes are located further away from the main channel and therefore more protected. Secondly, the excavation soil from the channel can be used entirely for the construction of the dykes. This way it is possible to achieve the maximum discharge area by moving the minimum amount of soil.

   ⇒ $A_{D1} + A_{D2} = A_{H2}$

5. Optimization of the embankment of the main channel

   In shallow areas with a low slope, the depth of the water (h_H und h_V) should not be too high, while, at the same time achieving the maximum runoff. In trapezoid channels, the maximum hydraulic radius is reached at m = 0.577. This steep slope is possible with an embankment made out of cement. This leads to high water levels as a side effect. The following chart shows the depth of the water as a function of the runoff with three different embankment slopes ratios (1:1; 1:3; 1:5):



In this example the trapezoid channel is 10 m wide with a slope ratio of 1:10 000.

Source: *Malcherek Andreas, Fließgewässer - Hydromechanik und Wasserbau, Institut für Wasserwesen, Universität der Bundeswehr München.*

Due to the low slope of the embankment, the whole channel is wider, because of the bigger main channel slope area (B_2). This lowers the water level and decreases turbulences in the water stream between the main channel and the foreshore area. Therefore, the main channel can reach the maximum depth of:

$$h_H = 2\ h_V$$

The required area for the channel is getting larger when m is increased. An increase of one m increase the area requirement of the channel by ($2*hH_2$) *length of the channel considered. A limit is reached at $\boldsymbol{m_H}$ **= 6.**

Even in the case of wide floodplain areas, the separation area between the floodplain areas and the main channel can be neglected under the above-mentioned conditions. However, the effluent must be calculated according to compound channel with the sum of the zonal discharges. Kradolfer (1983) In order to estimate for a compact channel, without division, the width of the whole floodplain areas is limited to the width of the main channel:

$$B_H = B_V$$

Formulas

Cross section area of the dykes:

$$A_D = 2\,[(2\,m\,f_D + B_{DK})\,h_V + m\,h_V^2 + B_{DK}\,f_D + m\,{f_D}^2\,]$$

Cross section area of the main channel: below the reference level

$$A_{H2} = B_H\,h_{H2} + m_H\,{h_{H2}}^2$$

Cross section area of the whole channel:

$$A = (\,2\,m_H\,h_{H2} + B_H)\,h_V + B_H\,h_{H2} + B_V\,h_V + m_H\,{h_{H2}}^2 + m\,h_V^2$$

After applying the geometric specifications…:

- $A_D = A_{H2}$
- $B_H = B_V = \boldsymbol{B}$
- $h_{H2} = h_V = \boldsymbol{h}$
- $B_{DK} = 4\,;\quad f_D = 1\,;\quad m = 3\,;\quad m_H = 6$

…it results in…:

$$A = 21\,h^2 + 3\,B\,h$$

…and:

$$B = \frac{14}{h} + 20$$

The result of A can be shown as solely dependent on h:

$$\boldsymbol{A = 21\,h^2 + 60\,h + 42}$$

Wetted perimeter:

$$P = 2\left(\sqrt{m^2 + 1}\;\,h_V + \sqrt{{m_H}^2 + 1}\;\,h_{H2}\right) + B_V + B_H$$

After applying the geometric specifications and solely dependent on h:

$$P = 2\,\left[\left(\sqrt{10} + \sqrt{37}\right)h + \tfrac{14}{h} + 20\right]$$

$$\boldsymbol{P = 18{,}49\,h + \frac{28}{h} + 40}$$

Numeric investigation

The hydraulic radius R and the cross section area A are necessary for the calculation of the amount of discharge. R is dependent on A which leads to the need of an iterative approach of h_H in the first step. Therefore a table of A- and R-values as a function of the maximum water depth h_H is helpful.

Water depth in the main channel h_H [m]	Cross section area A [m^2]	Perimeter P [m]	Hydraulic Radius R [m]
2	123	86.5	1.42
4	246	91.0	2.70
6	411	104.8	3.92
8	618	121.0	5.11
10	867	138.1	6.28

Another influencing factor is the surface roughness of the channel. According to the Manning Formula from Gauckler-Manning-Strickler, the surface roughness is considered in the factor k_{st} with the unit [$m^{1/3}$/s].

Average stream velocity V_m according to Gauckler-Manning-Strickler:

$$V_m = k_{st} \cdot R^{\frac{2}{3}} \cdot I^{\frac{1}{2}}$$

I: Slope of the stream [m/m]

Examples for the surface roughness factor according to Strickler:

Channel type	**k_{st} [$m^{1/3}$/s]**
Cement screed	100
Concrete with timber lining	65 to 70
Normal quarry-stone-construction	60
Cobbled quarry-stone embankment on a sand bed	45 to 50
Soil with coarse stones	25 to 30

Source: Schneider Bautabelle, Bundesanzeiger Verlag

Calculation example

Monsoon-flood-water-channel:

$Q = 1600\ m^3/s$ (Equal to the discharge of the Danube on 25.05.2017 in Passau Ilzstadt)

I = 0.1 ‰ (10 cm descent in 1 km)

From the table and the formulas of Manning-Strickler:

$k_{st} = 60$

Water depth in the main channel h_H [m]	Stream velocity V_m [m/s]	Discharge Q [m^3/s]
8	1.78	1100
10	2.04	1770

⇨ $h_H = 10$ m offers 10 % back-up

Dimensions of $h_H = 10$ m	
Width of the riverbed B_H	24.8 m
Width of the floodplain areas (left and right: ½B_V)	12.4 m
B_1	15.0 m
B_2	30.0 m
Embankment top (dyke top) B_{DK}	4.0 m
Freeboard f_D	1.0 m
Width of the dyke at the baseline (z = 0 m)	34.0 m
Width of the dyke at the water level	10.0 m

Note:

In shallow terrain or in areas where higher discharge volumes are required the channel can be created more broadly proportionally to the depth h_H. In this case the embankment top B_{DK} and the freeboard f_D will be larger which is necessary due to the substantial width of the river (flow-pressure, waves and potential influences of errors in the design).

Amount of soil moved

The cross section of the soil orthogonal to the channel line results in:

$$A_D = A_{H2} = 6\,h^2 + 20\,h + 14 \quad [m^2]$$

For 1 m of channel with a depth of $h_H = 10$ m (h = 5 m) an amount of 264 m^3 of soil has to be moved. This equals exactly the amount of soil that is needed for the construction of the dykes.

The amount of soil that has to be moved to compensate a slope of ± 10 cm in the direction of the channel is calculated in the following:

$$V_A = 0{,}1 \cdot 2\,(B_{DK} + 12\,h + B)$$

In this example approximately 17.8 m^3 of soil have to be moved to compensate the slope. It must be noted, that while compensating the slope, the amount of excavation is insufficient for the amount of soil that is needed for the embankment.

Enhancements

For the calculation of other variants of cross sections, it is necessary to deploy the formulas depended on the width of the embankment top (dyke top) B_{DK} and the freeboard f_D.

For the whole area A the width of the main channel or the whole width of floodplain areas and the perimeter P the following formulas are applied:

$$A = Q_1 h^2 + Q_2 h + Q_3$$

$$B = \frac{Q_3}{3\,h} + \frac{Q_2}{3}$$

$$P = 2\left(Q_4\, h + \frac{Q_3}{3\,h} + \frac{Q_2}{3} \right)$$

with:

$$Q_1 = 7\,m$$

$$Q_2 = 6\,(2\,f_D\,m + B_{DK})$$

$$Q_3 = 6\,f_D(\,f_D\,m + B_{DK})$$

$$Q_4 = \sqrt{m^2+1} + \sqrt{(2\,m)^2+1}$$

$$m_H = 2 \cdot m$$

Example

For a higher discharge while having less depth but larger width of the channel, B_{DK} and f_D are applied as follows:

B_{DK} = 8.0 m

f_D = 2.0 m

Which results in:

$$Q_1 = 21$$

$$Q_2 = 120$$

$$Q_3 = 168$$

$$Q_4 = 9.245$$

The formula for the calculation therefore is:

$$A = 21\,h^2 + 120\,h + 168$$

$$B = \frac{56}{h} + 40$$

$$P = 18.49 \cdot h + \frac{112}{h} + 80$$

For different depth of the water h_H in the main channel, an Inclination of I = 0.1 ‰ and a roughness of k_{st} = 60 (according to Strickler) the following values result:

Water depth in the main channel h_H [m]	Cross section area A [m^2]	Perimeter P [m]	Hydraulic Radius R [m]	Stream velocity V_m [m/s]	Discharge Q [m^3/s]
2	309	210.5	1.47	0.776	240
4	492	173.0	2.84	1.20	590
6	717	172.8	4.15	1.55	1111
8	984	182.0	5.41	1.85	1820
10	1293	194.9	6.63	2.12	2741

In this example a discharge of Q = 1600 m^3/s with a depth of the main channel of 8 m is easily possible. The additional freeboard is not in use. Hence, it is possible to increase the water level by one more meter with the remaining freeboard of f_D = 1.0. This leads to a significantly higher cross section area A, a just fractionally higher perimeter P and larger hydraulic radius R. This method is used in the following.

Method for h_V > ½ h_H

The described method fulfills the requirements for the calculation for a compact channel even better and the flow properties get better as well.

For the calculation, a new variable Z_D is introduced. Z_D is depended on the freeboard f_D and the additional water depth h_Z (as described before).

$$Z_D = h_Z + f_D$$

The additional water-bearing cross section area is calculated with the following formula:

$$A_Z = h_Z \left[\frac{2}{3}\left(\frac{Q_3}{h} + Q_2\right) + 6\,m\,h + m\,h_z\right]$$

The additional wetted perimeter with:

$$P_Z = 2\sqrt{m^2 + 1} \cdot h_Z$$

With an embankment slope ratio of 1:3 ($m = 3$) the formulas for this method are:

$$A = 21\,h^2 + Q_2 h + Q_3 + A_Z$$

$$B = \frac{Q_3}{3\,h} + \frac{Q_2}{3}$$

$$P = 2\left(9{,}245\,h + \frac{Q_3}{3\,h} + \frac{Q_2}{3}\right) + P_Z$$

with

$$Q_2 = 6\,(6\,Z_D + B_{DK})$$

$$Q_3 = 6\,Z_D(3\,Z_D + B_{DK})$$

Calculation example for $h_V > ½\, h_H$

The following magnitudes are used for the calculation:

$B_{DK} = 6.0$ m

$f_D = 1.0$ m

$h_Z = 3.0$ m $\Rightarrow$ $Z_D = 4.0$ m

$I = 0.1$ ‰

$k_{St} = 60$

Q_2 and Q_3 result in:

$Q_2 = 180$ [m]

$Q_3 = 432$ [m^2]

The results are shown in the table below depended on the water depth in the main channel below reference level and the depth in the main Channel h_H:

Water depth in the main below reference level area h_{H2} [m]	Water depth in the main channel h_H [m]	Cross section area A [m^2]	Perimeter P [m]	Hydraulic Radius R [m]	Stream velocity V_m [m/s]	Discharge Q [m^3/s]
1	5	1938	446	4.35	1.60	3100
2	7	1803	320	5.63	1.90	3425
3	9	1998	290	6.89	2.17	4335
4	11	2307	285	8.09	2.42	5583
5	13	2687	289	9.30	2.65	7130

When the depth of the main channel is not exceeding 1 m relative to the ground level of the floodplain area, the amount of excavation is not enough for the construction of the dyke. Hence, the width of the channel has to be larger (h_{H2} = 1 m results in B = 204 m). With a lower main channel and therefore more excavation, the cross-section area gets smaller even though the dykes have to be higher. The case of h_{H2} = 3.0 m (marked yellow above) will be examined more closely.

For h_{H2} = 3.0 m the dimensions result in:

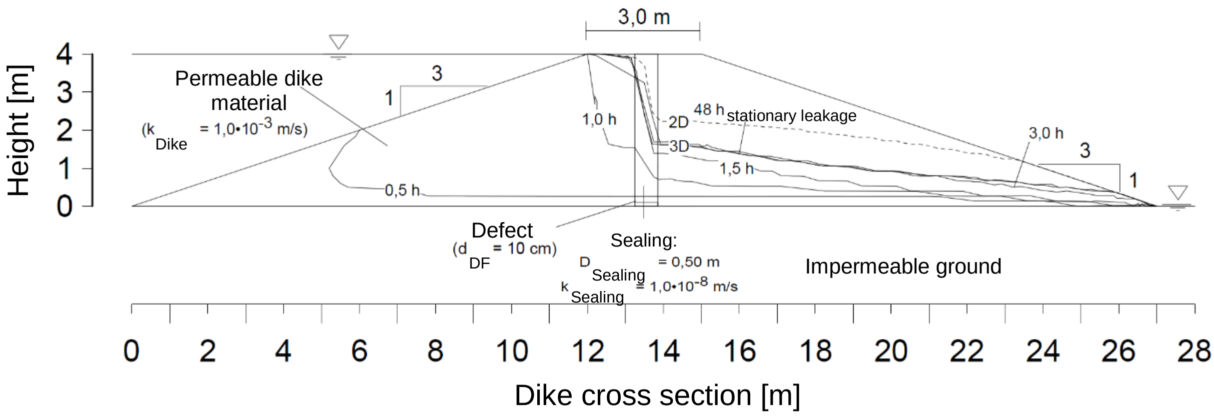
Dimensions for h_H = 9 m	
Discharge at a water level of 9 m (z = 6 m)	4335 m^3/s
Discharge at a water level of 3 m (z = 0 m)	430 m^3/s
Depth of the excavation	3 m
Height of the dyke	7 m
Width of the main channel B_H	108 m
Width of the floodplain area on the left and the right ½B_V	54 m
B_1	18.0 m
B_2	18.0 m
Embankment top B_{DK}	6.0 m
Freeboard f_D	1.0 m
Width of the dyke at the base (z = 0 m)	48.0 m
Width of the dyke at water level	12.0 m
Embankment slope ratio	1:3
Main channel slope ratio	1:6
Amount of soil moved per meter	378 m^3

The demand for huge amount of excavation at small depth of the main channel can only be met with a large width of the channel. The following table shows the correlations:

Width of the channel depended on the depth					
Depth beneath the floodplain areas h_{H2} [m]	1	2	3	4	5
Depth of the water in the main channel h_H [m]	5	7	9	11	13
Discharge Q [m^3/s]	3100	3425	4335	5583	7130
Width of the water surface [m]	444	318	288	282	286

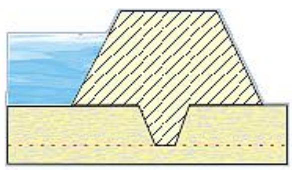
Important consideration

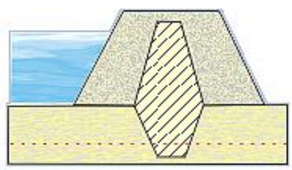
The condition $A_D = A_{H2}$ which is the base of these calculations, should not imply that the dyke can be solely constructed from the excavation of the main channel (e.g. by simple depositing and reinforcing). Dykes serve for the temporary dam of water (DIN 19712). For the example above ($h_{H2} = 3.0$ m) at a discharge of 430 m^3/s a seepage of the dyke is inevitable. The duration and the water pressure determine the seriousness of the leakage. Furthermore, it should be mentioned, that even a small defect in the sealing of the dyke can have severe consequences.

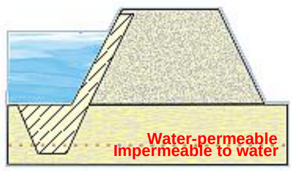


Dyke with sealing and a defect in it with the consequence of leakage: (Haselsteiner, 2007)

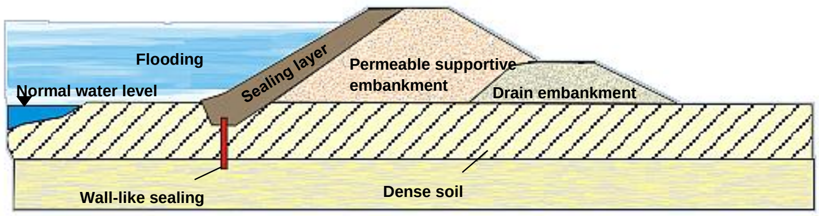
Examples of dykes (Glock, 2017):


Simple dike (Sand, clay)


Inner sealing (Clay, asphalt, concrete)



Surface sealing (Clay, asphalt, concrete)



Three-zones-dike