The Framework for Integrated Water Management in the Thua Thien-Hue Province

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SUMMARY

The Thua Thien-Hue province is located in the centre of Vietnam. It is characterized by the short distance between the mountains in the west and the coast of the South China Sea in the east. Two large rivers flow through the province, fed by multiple smaller rivers from the mountains. The Bo River flows through the northern part of the province and ends up in the Cau Hai lagoon. The Huong River is the largest of the two and flows through Hue city ending in the Cau Hai lagoon.

The coastal zone of the Thua Thien-Hue province knows a lot of water related problems, like salt intrusion and drought in the dry season and both pluvial and alluvial flooding in the rainy season. Tackling these problems requires an integrated approach that considers all problems, functions and stakeholders. This project will aim to apply a Framework for Integrated Water Management to the Thua Thien-Hue province to minimize the water related problems in the future.

This framework assigns different return periods for flooding per area. An area with a high population density will suffer more damage during a flood than a rice paddy, and should have a smaller chance of flooding in order to make the water defence system economically justifiable. This way, a map is created that indicates the desired chance on flooding throughout the coastal, flood prone area of the Thua Thien-Hue province.

Using a SOBEK 2D model, the flooding can be simulated. The results from this model show that the amount of water that enters the area is too large to apply traditional protection by raising dikes. Also, most houses are built near the riverbanks, making the implementation of dikes problematic. Two possible solutions were considered. The first, consisting of two bypasses, showed unrealistic as the capacity of the second bypass was insufficient. The second scenario, called “Lake Hue”, uses a reservoir as a retention area during extreme events. A dam regulates the discharge towards Hue City while a spillway towards an area with a lower population density takes care of excess water.

An initial cost benefit analysis, using the results from the SOBEK model, indicates a payback time of fifteen years. After the design lifetime of 50 years, the initial investment is returned twofold.

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PREFACE

In this report the results of a research project about the flooding's in the Thua Thien-Hue Province is presented. The project was part of the master program Hydraulic Engineering, Water management and Structural Engineering at the faculty of Civil Engineering at Delft University of Technology and was conducted in cooperation with the Water Resource University in Hanoi.
This project gave us the opportunity to work abroad in a different cultural environment. In the fourth week we had a fieldtrip to the city of Hue and its surroundings were we saw and learned a lot. Also apart from the project we visited many places and learned a lot from local students and people.

We would like to thank our supervisors for their time and effort they have put into the project. Dr. Mai van Cong from the Water Resource University for his supervision during the project. And Ir. H.J. Verhagen from the TU Delft which helps us a lot during the preparation of the project.

We also would like to thank Dr. N.T. Lam for the SOBEK input data we received, Ms. Hue for all her logistical support and guidance throughout the project and Ms. Hanh for her help during our fieldwork in Hue.

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CONTENT

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1. INTRODUCTION

1.1 PROBLEM DEFINITION

In South-East Asia a lot of countries suffer from water related problems. These problems are a result of ineffective water management, tough climate situations, climate change and human behaviour. For example the large scale deforestation and drainage of wetlands. This leads to different hydrological regimes in the river catchments and can cause major flooding problems in the downstream areas (Tran and Shaw 2007). The IPCC also predicts larger changes in the global climate, therefore increasing the chance that more water problems will occur in this area in the future (IPCC 2001). One of the countries that suffer a lot from water related problems is Vietnam. The location and climate of Vietnam makes the country very vulnerable for water related problems. In addition, water can have a lot of functions like irrigation, navigation and recreation. This makes this problem only solvable by applying an integrated approach for water management.

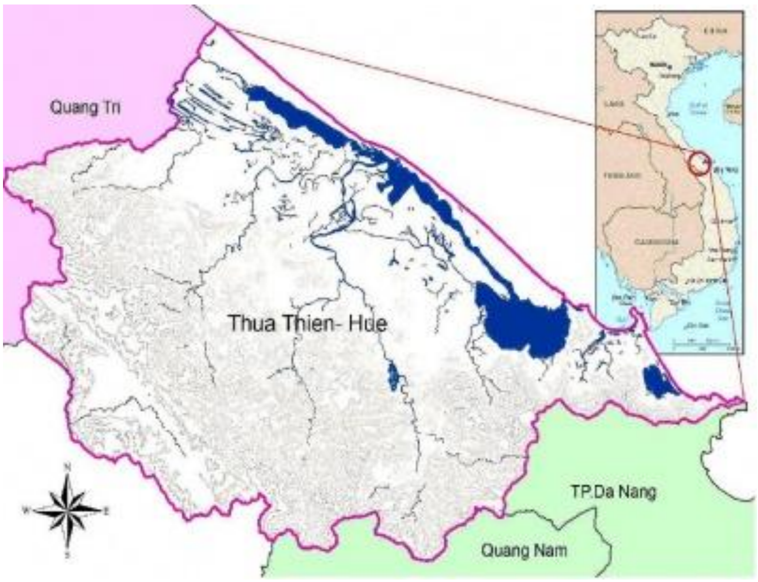


FIGURE 1: LOCATION OF THUA THIEN HUE PROVINCE IN VIETNAM AND THE SURROUNDING REGIONS (TRAN AND SHAW 2007)

At this moment, the water related problems are estimated to cost the government 1.5% of the GDP each year and many human lives (Shaw and Sonak 2006). In Vietnam the approach for the northern part of the country differs from the approach for the South. The policy for the Northern part is to strengthen the dike system and flood retardation and to protect essential densely population and economic areas against floods. In the Southern part of Vietnam the policy is to prepare measures for living with floods to minimize the water damage. For the Central part of Vietnam it is very difficult to follow a certain policy. This is due to the narrow and topographically complicated land, which is frequently affected by storms and flooding. (Shaw and Sonak 2006). In this report one of the 14 provinces of Vietnam is investigated to come up with a water framework to reduce the water related problems.

One of the provinces in Central Vietnam is called The Thua Thien-Hue province. This province is situated in the centre of Vietnam (Figure 1) and has a high risk from disasters and climate change-related problems. The Thua Thien-Hue province is characterized by high mountains of about 1700 meters above sea level on the east side and a flat coastal plain on the west side. The most important river in the area is called the Huong River and flows through the city of Hue. This river is very important for the people in an economical point of view, because they use the river for fishery, tourism, agriculture and serves as a sewage system.
The city of Hue, which is the largest city of this province, was the capital of the former imperial kingdom. This is why a lot of ancient buildings are located in the city centre, which refers to the former imperial capital. At this moment, the province suffers from floods, typhoons and

droughts (see also appendix C). The damage of the flood disaster events of the last years are shown in Table 1 .

TABLE 1: LATEST FLOOD DISASTERS IN THE THUA THIEN-HUE PROVINCE (THANH)

Year	Killed	Estimated loss (billion dong)	Year	Killed	Estimated (billion dong)
1990	18	56	**2001**	5	18
1991	10	20	**2002**	9	15
1992	8	12	**2003**	5	27
1993	6	14	**2004**	10	248
1994	1	1.2	**2005**	7	158
1995	20	60	**2006**	9	2931
1996	31	127	**2007**	23	1162
1997	1	11	**2008**	5	62
1998	31	169	**2009**	17	378
1999	352	1762	**2010**	15	227
2000	4	77	**2011**	13	799

In the most recent example of its destructive force, the latest typhoon called Haiyan killed more than 30 people. This all concludes that an integrated water framework is needed in this area to reduce the water damage and make the province a safer place to live in. But this is not so easily done in this province. From a geographical point of view, the area is very difficult to protect from flooding. Because of the short distance between mountain and sea, the time between precipitation and related river outflow in the sea is very short. In combination with the unlucky location of the province, inside a typhoon prone area, often results in floods in the city centre and the agricultural land around the city.

Just like most of the Asian countries, life in the rural areas of Vietnam depends on agriculture. This leads to additional challenges for the framework for water management, because a farmer who loses his revenues every year because of the water, will slide into a vicious circle of poverty (Shaw and Sonak 2006). An integrated water framework will not only improve the safety of the people but also the wealth of the area. The farmers will also most likely be the ones who suffer the most from the climate change (Shaw and Sonak 2006). It is very important to pay attention to the impact of climate change on the livelihoods, and re-establish the links between wealth, livelihood and environment.

An additional advantage of improving the flood controllability of the province is that a company is not willing to invest in an area where his investment is damaged by water numerous times per year. So by improving the control over floods, companies will be more interested in an investment in this area. This will increase the economic potential of the province.

Another issue in the province is the environmental related water problems. One of the problems is the Tam Giang-Cau Hai lagoon, which is the largest lagoon system in South-East Asia. The water quality of the lagoon system has rapidly degraded due to the changing environment and the expansion of the aquacultural sector. Also the construction of a major anti-salinity weir in the Huong River is decreasing freshwater flows from downstream. This also has an impact on the fauna and flora in the lagoons (NCAP 2012), because the lagoon becomes more saline .

This all leads to the conclusion that this province deals with a lot of water related problems due to the geography of the province, land use and the extreme climate. This report will give an integrated approach to come up with a framework for a part of this province.

1.2 THE PROJECT

As mentioned in the preface, this project is part of the master program Hydraulic Engineering, Water management and Structural Engineering at the faculty of Civil Engineering at Delft University of Technology. In cooperation with the Water Resource University in Hanoi a framework of integrated water management will be set up for a part of the Thua Thien–Hue Province. Because there are a lot of challenges in this area, this report will be mainly focussed on flood. All information used in this report is collected from literature, discussions with experts, interviews and a field trip to the Thua Thien-Hue province. In the remaining of this chapter the project area boundaries will be given. Also the current climatology and the prediction for the future will be given for the project area. This chapter outlines the major problem in this province with regards to the water control, due to a topographically challenging landscape, climate change, and the number of stakeholders, which make the province very vulnerable for flooding and difficult to control.

Chapter 2 consists of three parts and introduces the framework of Integrated Water Management to the Thua Thien-Hue province. First, the definition of a principle of a water framework is explained. Secondly, the current situation in the province will be shown, which includes: land use maps, current structures against flooding and the flood maps. The information needed for making a land use map and the information needed for the summation of the current structures are obtained during the field trip and a literature study. And lastly, the framework will be applied. With the use of the land use map, height map and a map with important infrastructure in the province, areas can be determined in which each area has its own level of safety expressed in a return period. Furthermore, some possible solutions to get these desired return periods will be summed with reference projects.

In the first two paragraphs of chapter 3, an overview of the technical possibilities for the two scenarios is given, it continues with the calculations of the volume of the reservoir that is obtained from rainfall data and discharge date. After the dimensioning, the two scenarios will be modelled and computed with use of the SOBEK software suite. After the calculations the consequences of the two scenarios on some hydrological function will be given. In the remainder of chapter 3 a cost-benefit analysis is given as well as a paragraph about the flood resistance of buildings.

In Chapter 4 the conclusion are drawn and recommendations will be given, also some possible following up studies will be shown.

In an integrated water management approach a strong link of feedback and interaction between Hydraulic Engineering, Structural Engineering and Water management is needed. However, this is unfortunately not possible due to the short time available for making the project.

1.3 THE PROJECT AREA

The province Thua Thien-Hue has an area of 5062km^2 and is located in the centre of Vietnam. The province has many kinds of geography like: forested mountains, hills, rivers, paddy fields, coastal lagoons and marine areas (Tran and Shaw 2007). When one has to characterize the province geomorphologically one can divide the area in three areas, namely the higher mountain area (25 kilometers wide), low-lying area (19 kilometers wide) and the coastal plain (15 kilometers wide)(Villegas 2004). The mountains in the east have an altitude between 200 and 1700 meters. These geographical changes lead to very steep slopes in the riverbeds which improves the drainage capacity of the rivers, while in the coastal plain the riverbeds are very flat. Around one million people live in the province and 340.000 of them live in the city of Hue. The densest populated areas are located along the coast in the coastal plain; furthermore, this coastal plain has a lot of agricultural and industrial land, which makes the area more attractive in an economical point of view. Four major rivers flow through the province, of which the Huong River (Perfume River) is the largest. In Figure 2 the important names in the Thua Thien-Hue Province are shown.

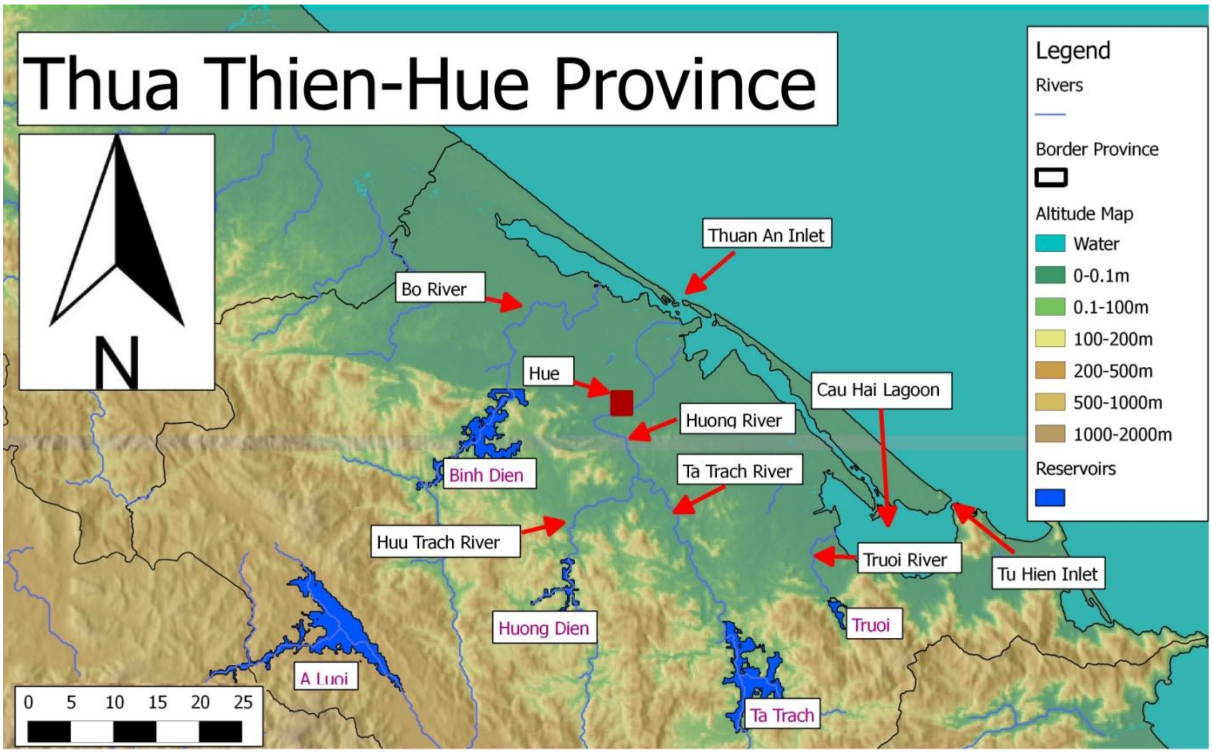


FIGURE 2: THE THUA THIEN HUE PROVINCE WITH THE IMPORTANT NAMES

To make a water framework for the whole province would be time consuming and less necessary in the mountainous areas. One needs to aim on a smaller region. Especially if there is a limited time available to carry out the project. Therefore, the project area consists only of the coastal plain of the Thua Thien-Hue province for the following reasons. First, the major floods mainly occur in the lower region of the province (see Figure 19 and Figure 22) where most of the people live. Therefore, this area needs a higher safety standard by protecting or coping with a flood. Secondly, most agricultural and economical valuable land is located in this area. This makes it the area where a good water framework is most necessary to get less economical damage. Thirdly, in the mountainous areas the floods are mainly occurring locally and because of the high drainage capacity of the rivers the water is quickly transported to the coastal plain. And finally, a fine height map is available for this area which can be used in the SOBEK model to get a more accurate model than one should have in the mountainous areas. This is why the investigated area of this project only maintains the coastal plain of the Thua Thien-Hue province. This area is also shown in Figure 3. Most of the people in the province live inside the coastal plain and also the city of Hue is located here. Around the city a lot of agricultural and aqua cultural areas are located. More on the land use is described in the land use chapter of this report. The project area stretches along 70 kilometers of coastline and about 15 kilometers inland. This makes the total area of the coastal plain about 1050 square kilometers. To come up with a framework also structures outside the project area but within the watersheds are used (for example some reservoirs), because those structures can also protect the more downstream located coastal plain against flooding.

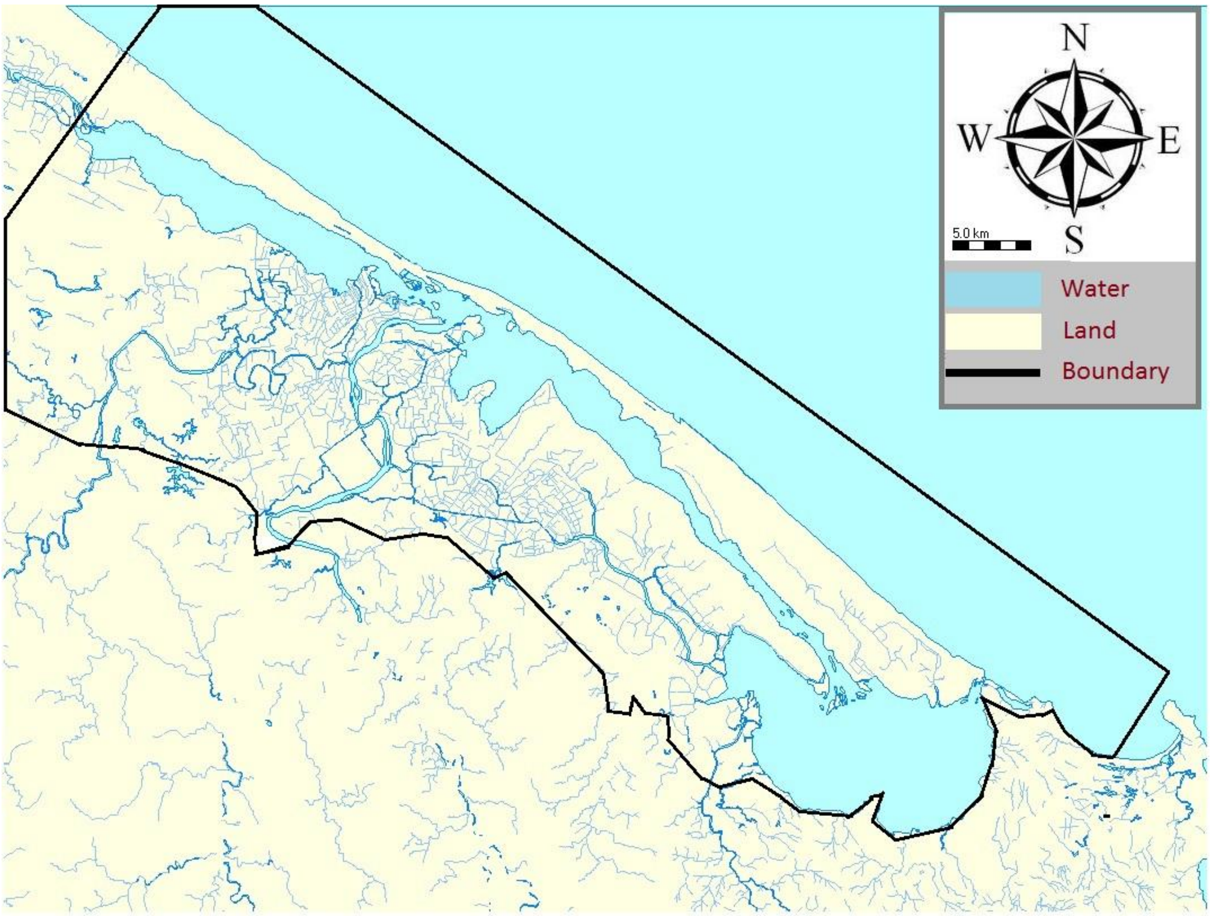


FIGURE 3: THE BOUNDARY OF THE PROJECT AREA WHICH CONSIST OF THE COASTAL PLAIN OF THE THUA THIEN-HUE PROVINCE

1.4 CLIMATOLOGY OF THE PROJECT AREA

The climate in the Thua Thien-Hue province makes the province one of the most disaster prone areas in Vietnam (Tong, Shaw et al. 2012). The average temperature, precipitation and relative humidity in this province is shown in Table 2.

TABLE 2: THE AVERAGE CLIMATE CONDITIONS FOR HUE (WEATHERBASE 2013)

	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Low Temperature (°C)	21	17	18	20	22	23	25	25	24	23	22	20	18
Average Temperature (°C)	25	20	21	23	26	28	29	29	29	27	25	23	20
Average High Temperature (°C)	29	23	24	27	30	33	34	34	34	31	28	26	23
Average Precipitation (mm)	2980	180	90	60	60	80	90	50	130	500	680	640	370
Average Relative Humidity (%)	79	87	87	84	79	74	69	67	70	79	84	84	86

When looking at the average climate conditions, one will not see very large amounts of rainfall or a high temperature. The extremes that often can occur in this province cause the flooding. The extreme rainfall, for example during a cyclone, can be much higher in this province than the average climate condition shows in Table 2. The highest amount of rainfall on records are 731.3mm for the daily precipitation, 2451.7mm for the monthly precipitation and 5910.7mm for the yearly precipitation (Tuong, Kien et al. 2006). Changes in rainfall patterns are also shown in Vietnam due to the climate change. The annual rainfall is expected to increase considerably in the coming years (Nguyen 2006), while the monthly rainfall is decreasing in most of the country for the months July and August; this will increase the occurrence of droughts. Furthermore, the rainfall in September, October and November is increasing leading to the occurrence of more floods (MoNRE 2003).
The impact of the climate change is summarized below (IMH 2005):

- The temperature is estimated to increase by 2.5°C by year 2070. Inland temperature will increase by 2.5°C meanwhile the temperature of coastal area will increase by 1.5°C.
- Annual average temperature and the absolute minimum temperature would also increase; furthermore, the number of days with temperature higher than 25°C will increase. This will affect the ecosystem and farming season.
- Due to increasing temperature, the evaporation and transpiration rate will also increase. Rainfall would concentrate in the rainy season, while the rainfall in the dry season will decrease in the Central Vietnam and drought would occur more frequently.
- Sea level in Vietnam has increased by 5 centimeter during the past 30 years. The sea level would rise by 33 centimeter in 2050, 45 centimeter in 2070 and 1 meter in 2100.
- The climate change would lead to an increase in sea surface temperature in higher latitude region of Pacific Ocean. It will lead to more typhoons in the North-West Pacific Ocean and will have more effect on Vietnam.
- In the next decades, the sea surface temperature, which maintains wind speed in typhoon, is predicted to increase. So, the typhoon intensity would be stronger, especially in 'El Nino' phenomenon years.
- Over the past few years, the typhoons hit the Centre of Vietnam in October, which seems to be significantly different from the usual typhoon patterns.

In the Thua Thien-Hue province the severity and the frequency of disasters increases significantly when one looks at the records. During the 19th and the first half of the 20th century from 1804 to 1945, there were 38 floods and typhoons in the historical record. While, between 1975 and 2000, there were 41 disasters recorded, which includes one storm, 18 floods and 22 storm-floods (Do 2002). There is also a tendency that the disaster season comes earlier than before, as one can see in Figure 6. The trends of the annual temperature and precipitation in Hue are

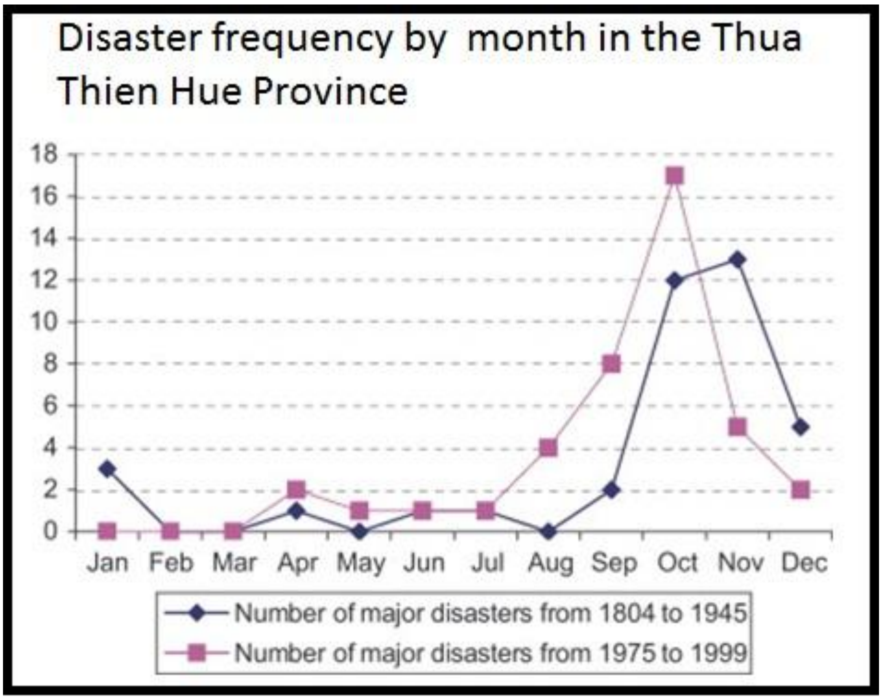


FIGURE 4: DISASTER FREQUENCY BY MONTH IN THUA THIEN HUE PROVINCE (DO 2002)

shown in Figure 5 and Figure 6 for the period from 1974 to 2004. In the dry season the rainfall decreases, but the rainy season has the largest increase in rainfall. These months were the major contributors to the total annual rainfall (Tuong, Kien et al. 2006).

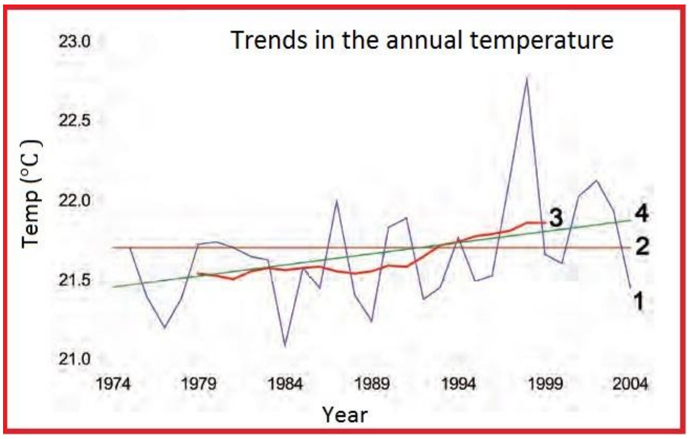


FIGURE 6: THE ANNUAL TEMPERATURE: VARIABILITY (1), CLIMATOLOGICAL AVERAGE (2), MOVING AVERAGE (TIME STEP – 11 YEARS)(3) AND LINEAR TREND (4) OF ANNUAL AVERAGE TEMPERATURE (TUONG, KIEN ET AL. 2006)

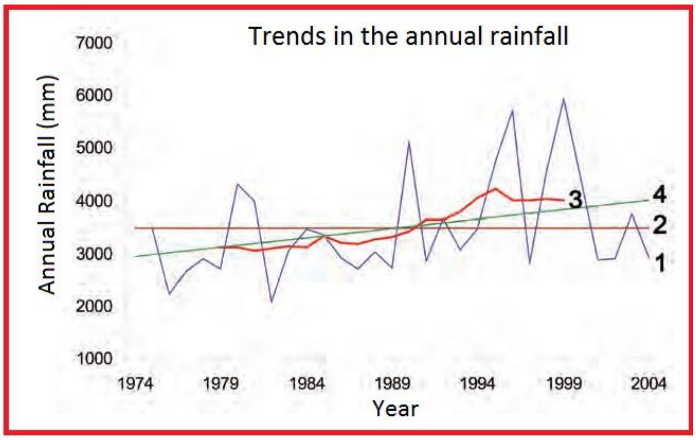


FIGURE 5: THE ANNUAL RAINFALL: VARIABILITY (1), CLIMATOLOGICAL AVERAGE (2), MOVING AVERAGE (TIME STEP – 11 YEARS)(3) AND LINEAR TREND (4) OF ANNUAL AVERAGE RAINFALL (TUONG, KIEN ET AL. 2006)

1.5 STAKEHOLDERS

There are a lot of people involved in the water related problems. This is due to the multiple functions that water can have for different people, so conflicting interests are inevitable. This makes a water related problem very complex to solve for everyone. In this paragraph a summary of the different types of stakeholders will be given. This list is far from complete and includes only the most important stakeholders, for a more extensive stakeholder analysis more research is needed.

1.5.1 GOVERNMENT

In Vietnam there are two ministries that are important in the framework for integrated water management.

- Ministry of Agriculture and Rural Development (MARD). The long term objective of the MARD is to achieve a large agricultural production. The products from the agricultural fields must be cultivated in a modern, efficient, sustainable, and must give high quality revenues. This should be done on the basis of advanced technology (MARD 2009). The floods in the wet periods and droughts in the dry periods are contradicting to the objective of the ministry. Their aim is a more evenly distribution of water during the year for the agricultural production. This ministry is also responsible for cooperation with relevant agencies in the field of disaster management (MARD 2007).
- The more recently created Ministry of Natural Recourses Engineering (MoNRE). The MoNRE is responsible for investigating the water recourses, monitoring the quality of the water and investigating climate change effects in the Thua Thien-Hue province. The ministry tries to counter the salt intrusion and the water pollution concerning domestic and agricultural purposes. Another aspect is sea level rise, which has effect on, for example salt intrusion. When the sea level rises, the salt intrusion will go further inland. Therefore, a sufficient high discharge during the year is in the interest of this ministry to guarantee a good water quality.

The approaches of the MARD and the MoNRE are significantly different with respect to flood protection. MARD has pursued more engineering-orientated approaches, while the MoNRE has a more integrated method for solving a water problem (Lebel, Sinh et al. 2009).

1.5.2 RESIDENTS

Approximately one million people live in the province of Hue. These people should be properly protected against flooding both from the river and sea. On the other hand, sufficient water should always be available to make the living possible and the quality of the river water must be sufficient, to guarantee the people's health. The inhabitants around the river use the river for multiple purposes like washing their cloths and cook dinner with the river water.

1.5.3 OWNERS OF THE DAMS

The multiple owners of the dams in the catchment area surrounding Hue are responsible for the water level in their reservoir. On one hand, the water level in the reservoirs must be high enough to be able to produce energy from hydropower to meet the needs of irrigation, prevent salt intrusion and have enough capacity for domestic use. On the other hand there has to be enough space available to store water in the rainy season. There are 5 dams and corresponding reservoirs. A summary of the reservoirs and the owners is given in Table 3.

TABLE 3: RESERVOIRS AND OWNERS IN THE THUA THIEN-HUE PROVINCE

Name of dam/reservoir	Owner
Truoi	Ministry of Agriculture and Rural Development (MARD)
Binh Dien	Song Da Corp. – Bac Ha Investment JSC, BItexco and Agrimeco
Ta Trach	Ministry of Agriculture and Rural Development (MARD)
Huong Dien	Huong Dien Hydropower JSC
A Luoi	Central Hydropower JSC

1.5.4 INDUSTRIAL WATER USERS

Not only residents in the province of Hue use water, there are also a lot of industrial users. They use the available water to create their products or use the water for cooling purposes.

1.5.5 FARMERS

During the dry season, the farmers need to have access to sufficient water for irrigation purposes. In the wet season the crops have to be protected against floods. Especially floods from the ocean are harmful since not only the power of the water destroys the crops, but the salinity of the environment also changes dramatically. Most of the crops need fresh water to grow, so if the ground becomes too salty, the harvest will fail and ground improvement is needed.

1.5.6 SHRIMPS FISHERY FARMS

The shrimps need brackish water in order to survive. This means that there should be some salt intrusion allowed from the sea. There is some friction between the requirements for the fishery farms and the requirements for the farmers.

1.5.7 SHIP NAVIGATION

Vessels up to CEMT class III make use of the Huong River. Therefore, the river should provide sufficient depth to cope with these vessels. Besides, the Thuan An inlet should be stabilized in order to keep the navigation going throughout the entire year.

1.5.8 ENVIRONMENTAL ORGANIZATIONS

Environmental organizations are investigating the results of human behaviour on the ecosystem and are monitoring if mitigation measures are taken. They aim towards a healthy ecosystem for people and animals. The areas more upstream of Hue in the more mountainous area have a very rich nature and ecosystem which must be remained. They also want more attention to be paid to decreasing the bad impacts on the fauna and flora inside the lagoon done by the poorly planned expansion of the aquaculture sector and constructions of dams and weirs.

2. THE FRAMEWORK FOR INTEGRATED WATER MANAGEMENT

In this chapter the principles of the Framework for Integrated Water Management will be clarified. When this principle is discussed, the current situation will be shown for the Thua Thien-Hue province. Following, the Framework for Integrated Water Management is applied for the current situation to come with some possible improvements. From this a combination of improvements will be formed, resulting in 2 scenarios. These scenarios will be worked out further in the next chapter.

2.1 THE PRINCIPLES OF THE FRAMEWORK FOR INTEGRATED WATER MANAGEMENT

When considering water related problems, many different views and specialities can be found. In an area close to the coast, the water related problems faced by the local population isn't just about defence against the sea or about preventing drought. This makes the situation much harder to control without amplifying not considered problems.

*This elaboration on the Framework for Integrated Water Management is based upon presentations given by **Mai Van Cong** (Water Resource University, Vietnam), **Wim Kanning** and **Han Vrijling** (Delft University of Technology, The Netherlands).*

2.1.1 SYSTEM APPROACH

To address this problematic situation, solving individual problems is costly, time consuming and only partly useful. Therefore, a system approach is needed. This system approach should consider all different uses and dangers of the nearby water. Based upon this analysis, a choice has to be made between different possible functions. This way, a plan can be made that optimizes the revenues and advantages of the water while minimizing the risk of harm or loss caused by the water in the region.

The downside to the use of this kind of approach is the needed input. To make a plan that includes all faces and uses of the water, input from all of these fields is required. Furthermore, a possible water management plan will cause different results for the fields considered. These fields include for instance flood control, agriculture, aquaculture, industry, housing and water quality among others. With in-depth research and multiple design loops an optimal risk-reducing, benefit-optimizing solution can be found. The aims of this approach show the diversity of the problem. These are formulated as:

- Flood safety
- Fresh water for agriculture
- Salt water for fish farming
- Facilitate shipping
- Facilitate recreation
- Nature conservancy
- Navigability of the rivers

As has been mentioned above, a large portion of these aims and other functions of water in the region interfere with each other, more often than not in a negative way. To facilitate these different functions, a clear understanding of the system and the desired functions is needed.

A design chart has been set up as a starting point for this kind of system engineering. This chart can be found in Figure 7.

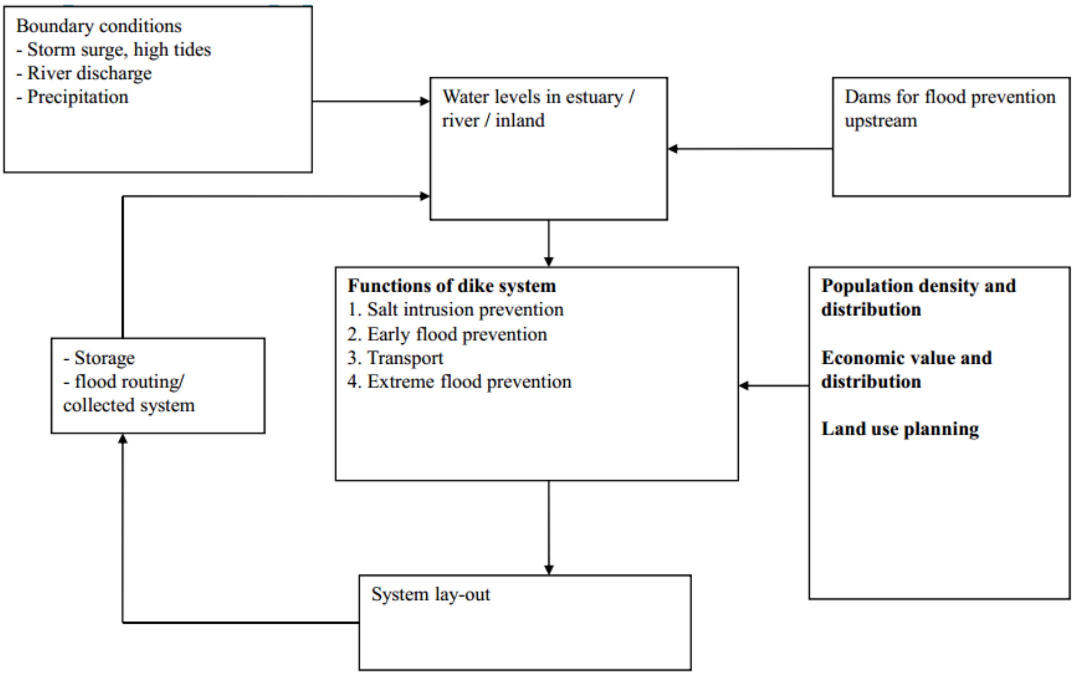


FIGURE 7: DESIGN CHART FOR SYSTEM APPROACH OF FRAMEWORK FOR INTEGRATED WATER MANAGEMENT (MAI 2013)

This chart starts at the top, where an analysis has to be made for the situation and influences in the region. Boundary conditions show the situation in the sense of water input from storms, river discharge and precipitation. Together with the appearance of dams and the lay-out of the current river- and lake system these boundary conditions lead to the water levels in the current system of rivers, estuaries and lakes.

The next step is to check whether this current situation and the current water levels comply with wanted functions set beforehand. This desired situation is based upon input from these fields, like demographic distribution, social preference, economic value of the different functions and the expected or planned future developments.

When the desired functions are made clear and are checked with the input from the current situation and in particular the boundary conditions, a system lay-out can be made, which can be used as a guideline for future developments in the region.

The expected future situation may change when the Framework of Integrated Water Management is used as a guideline for the region, changing the input of the model. Therefore, a feedback-loop is added from the resulting system lay-out, to incorporate changes in storage and flood defence system in the start of the model. Running through several design loops will result in a possibly agreeable system guideline for the region.

2.1.2 FLOOD PROTECTION

An important place in the Framework for Integrated Water Management is reserved for flood safety. The safety of the people surrounding the water and the people using the water is therefore the top priority of the organizations involved. This follows from the large consequences of a potential flood.

A rational, but somewhat unconventional approach is to look at areas with different grades of importance, in order to be able to sacrifice less important areas to keep the key structures and areas clear of damage. This follows from the given definition of the concept 'risk', which is defined as probability multiplied by the consequence. This definition automatically states that appointing an area with a low flood damage-potential the same risk of flooding as a city centre with high economic and social consequences would be an irrational choice, because the investment in the low flood damage-potential area would be a waste of money and time. Sacrificing low-value areas leads to a situation where not only not too much money is spent on defending lands without high value, but where these lands can also act as storage or spillway, lowering the risk of flooding for the high-value areas. This can be demonstrated by the single estuarine system.

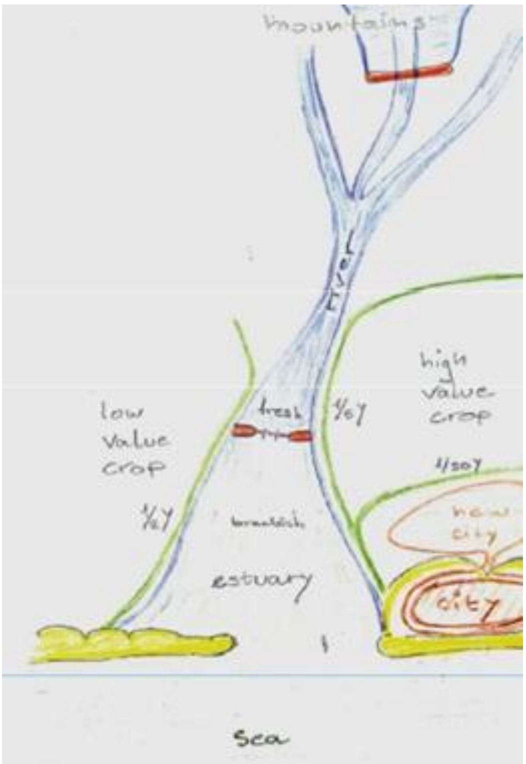


FIGURE 8: CONCEPT DRAWING OF THE SINGLE ESTUARINE SYSTEM (MAI 2013)

2.1.3 SINGLE ESTUARINE SYSTEM

This conceptual model consists of a single river catchment; this is also shown in Figure 8. Around the part of the river close to the sea, a city is situated together with some newly build suburbs, surrounded by different kinds of crop. As can already be seen, different return periods have been assigned to the areas. This period states the maximum flood level that the area is supposed to be able to withstand. For instance, high value crop is valued as a '1/5 y' area, which means that it should be able to withstand a flood that occurs approximately once every five years.

In a normal situation, only the river itself contains water. When a yearly flood occurs, the flood plain will act as storage. The dikes around each of assigned areas however are high enough to keep the crops dry. This changes however if the water keeps rising. When it passes the level of a 1 in 2 year flood, the low value crop will start to inundate, providing extra storage and therefore extra safety for the higher value crops. This effect increases when the water rises, where when the 1/50 year level is passed, only the most important city centre is still dry.

Because of these different steps in flooding probability, the cost of protection is optimized for the entire region. With minimal costs every area is protected up to the level to which it is worth to provide protection. This matters, because the total costs of a system are composed out of both investment costs and risk costs. By providing different steps in the safety of the flood defence system, minimal investment is needed to provide an optimal reduction of risk.

To provide this kind of protection, the system should be analysed and adjusted on a catchment basin level. A lot of problems can occur when the system is built from a more diversified profile than described here. An industrial area or a high populated area within the low value crop could pose different problems and individual attention. This also means that the framework should not be implemented once, but updated yearly. The main ideas and aims which follow from the findings of the framework should influence future developments in the area, when considering placement of new crops, houses, harbours, reservoirs and weirs.

The system approach will need a lot of input and detailed analyses from all different fields involved, but can pay out to serve as a backbone of a region where every function is optimally utilized, without the needless demise of conflicting functions within the most economical and socially sound solution.

2.2 CURRENT SITUATION OF THE THUA THIEN-HUE PROVINCE

This section of the report describes the current situation of the project area. First, the land use will be investigated. As mentioned before, the land use map is important for making the map with the desired return period. After this, the current water defence system in the province will be described; this will include only the main structures that prevent the province from flooding and drought that are already built or being built at the moment. Also, the current policy and organization is described. In the end of this section the resulting flood with the current water defence system and policy is shown. The improvements of the system in the last couple of years will be discussed and analysed. This will be done with the use of flood maps of 1999 and 2007, experience from the fieldwork and papers. Also, the SOBEK model is discussed in this section of the report.

2.2.1 LAND USAGE

The coastal plain of the Thue Thien-Hue province is very densely populated along the rivers. In the past most houses have been built very near the river. This is due to the multiple uses of the river water. The water is used for showering, washing and as sewerage. The agricultural land is mainly situated in the south side of the lagoon and exists mainly of rice fields. Some field are used only in the summer due to the frequently flooding of those fields in the winter. In the North-West of the coastal plain a big sand plain is located. No large populations or agricultural lands are located here. Along the lagoon a lot of aquaculture which cultivate shrimps is located. Because of the absence of a master plan for the systematic use of the land, the inhabitants suffer from multiple problems, like flood and drought. The new settlers use the land at their disposal for their own short-term benefits, resulting in the decreasing of the soil stability and also the ability of the soil and vegetation to retain water. This destructive manner of land use will lead in a more risk of flash floods, landslides, and droughts (Tran and Shaw 2007).

In order to find the desired return periods for the different parts of the project area, at first the current land use must be investigated. To come up with a land use map the following data is used: a detailed land use map from a report called “the Integrated Coastal Zone Management (ICZM) strategy for the Thua Thien-Hue province” (see Figure 9), Google Earth and the experiences during the fieldwork. The result is a more simplified land use map than the map of the ICZM, to get a clearer picture of the area. This makes the implementation of the framework much easier. The simplified land use map consists of just a couple of categories for the land use. At first the distinction has been made between urban areas and non-urban areas, based on the population density. The corresponding population densities are summarized in Table 4.

TABLE 4: POPULATION DENSITY RANGE OF THE DIFFERENT CATEGORIES

Category	Type	Population density (habitants/km^2)
Urban Area	City/Large population density	1000+
	Average population density	200-1000
Non-Urban Area	Low population density	0-200

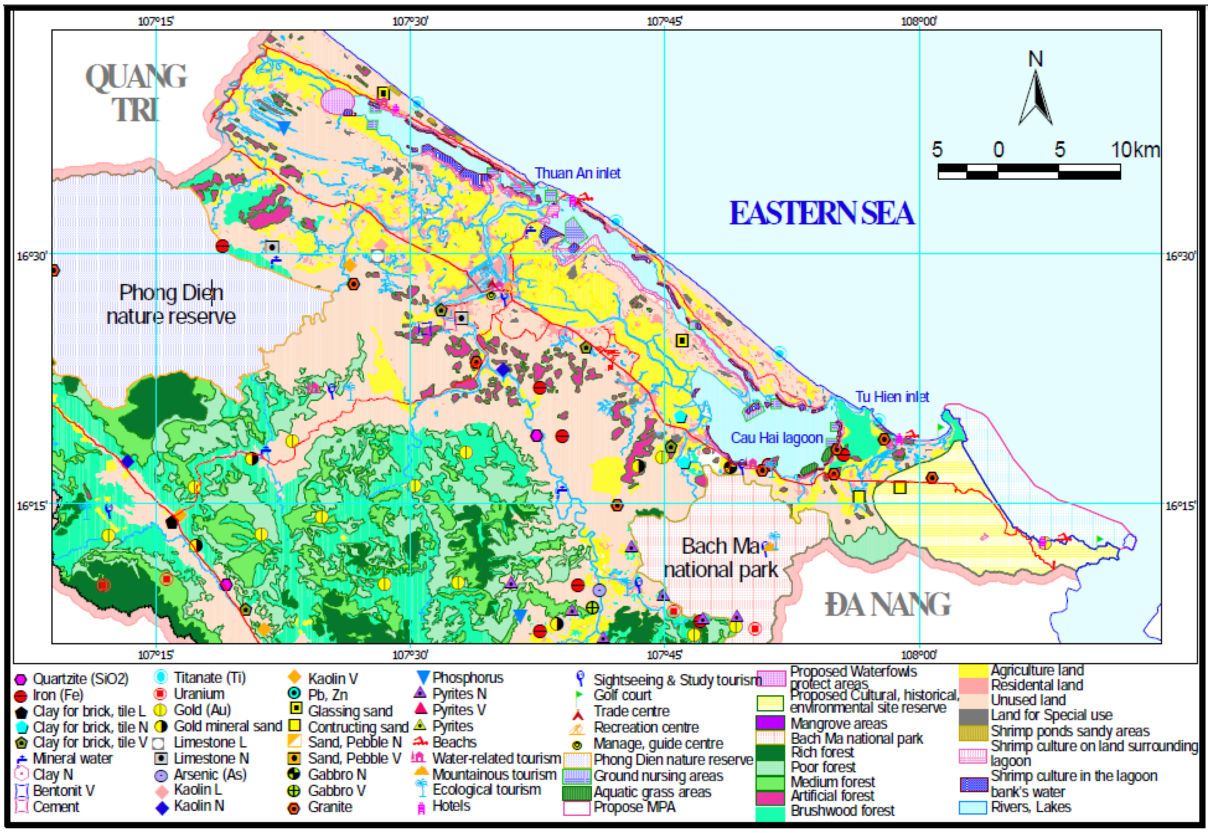


FIGURE 9: DETAILED LAND USE MAP (ICZM 2004)

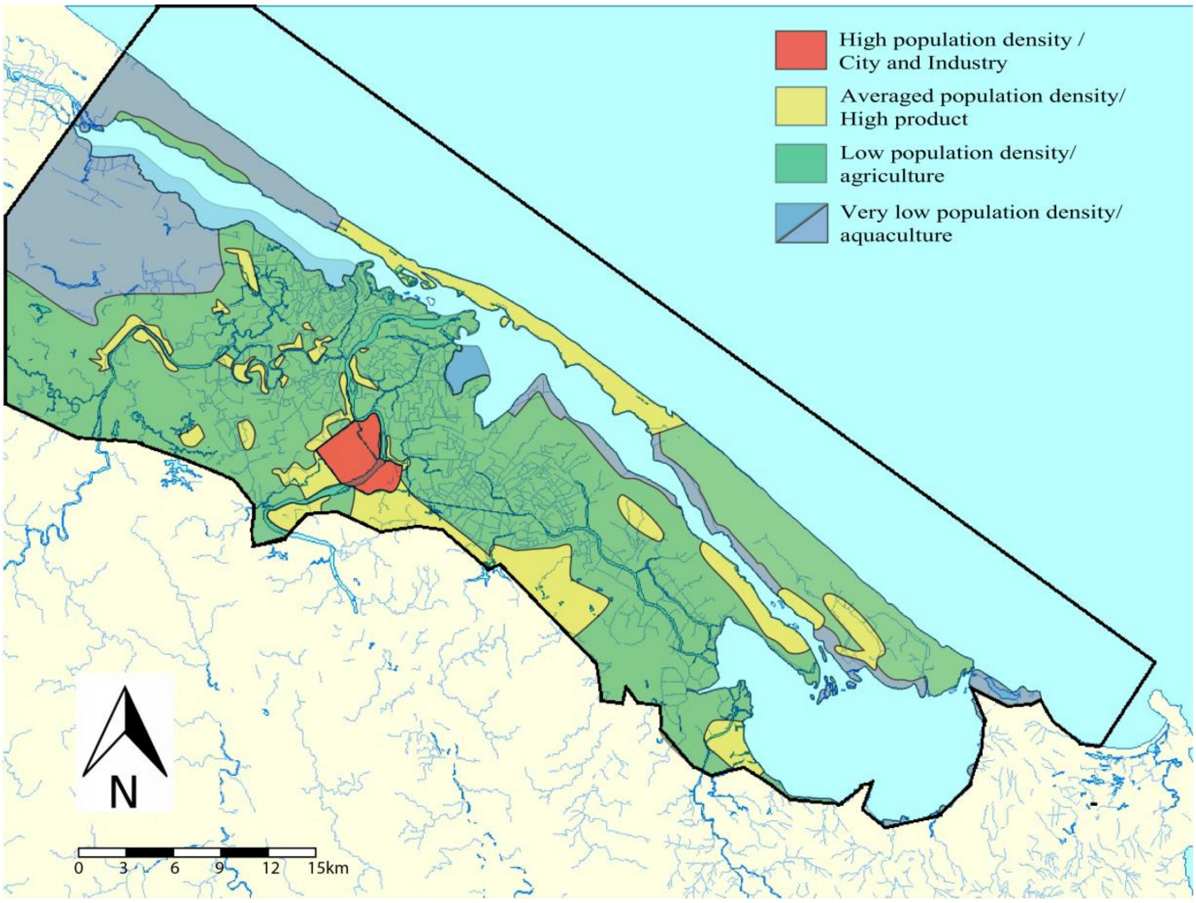


FIGURE 10: THE LAND USE MAP FOR THE COASTAL PLAIN IN THE THUE THIEN-HUE PROVINCE

During the field trip it turned out that there were no significant differences in economic value in the non-urban areas. For this reason, the only distinction that is made for the non-urban areas is the distinction between the aquaculture and agriculture.
Also a map is made to indicate the important infrastructure in the coastal plain. The result of the analysis is shown in Figure 10 and Figure 11.

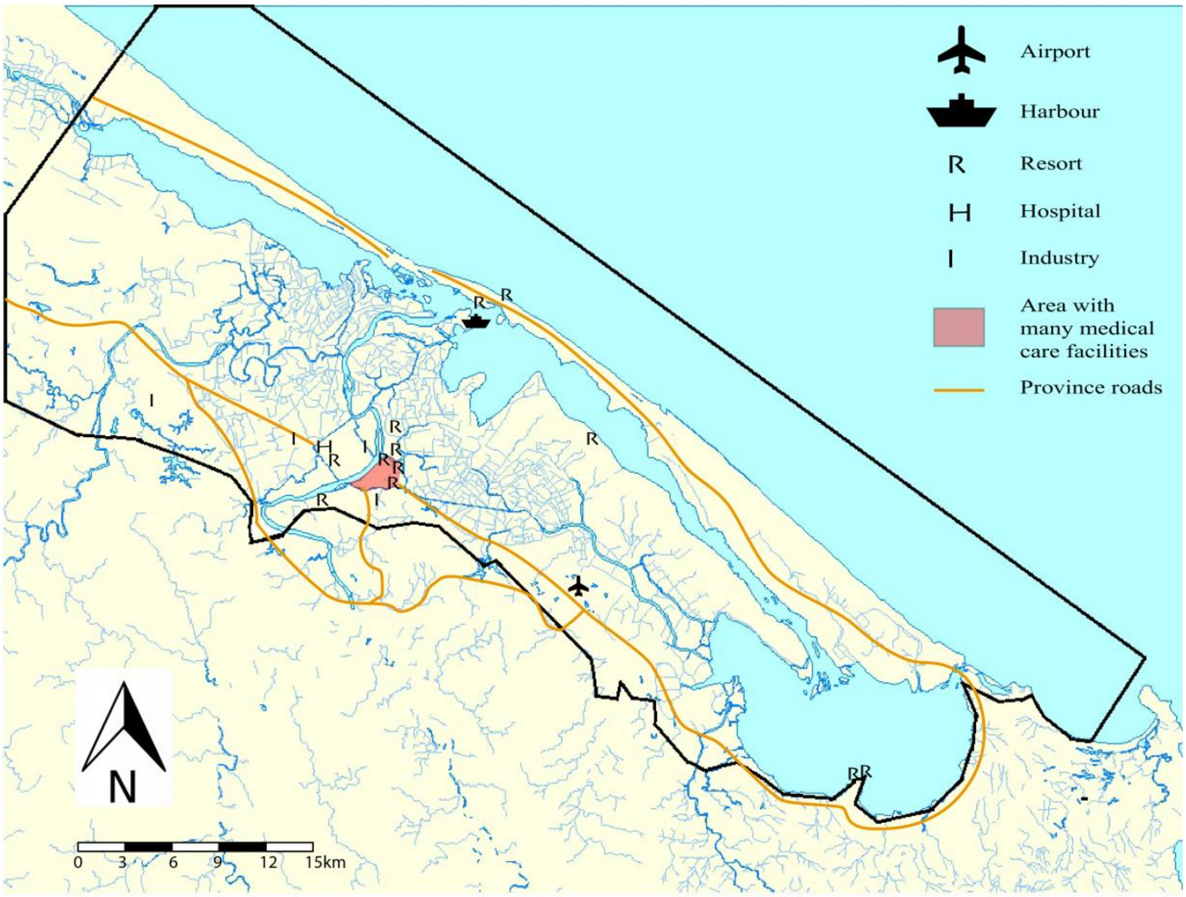


FIGURE 11: MAP WITH THE IMPORTANT STRUCTURES IN THE COASTAL PLAIN

From the analysis the following can be concluded: Firstly, the most densely populated part of the project area is the old centre of the city of Hue and along the rivers, where the largest river of the region, the Huong River, meanders right through the old part of the city. Apart from the inhabitants, there are also some important buildings like hospitals, industries and a few large resorts located in this area. The old city covers approximately 65 km^2. Secondly, the area around the old centre can best be described as an expansion area of the old city: at current, the density of the population in this ring ranged from average to high. This area is expected to grow even further in the future (Mai 2013). This area is at present more or less as big as the old city.

Thirdly, the strip around the lagoon is also quite densely populated. This densely populated strip has a width of almost a kilometre and is known for the large amount of shrimp farms. These are located around the lagoon because the shrimps need a brackish environment in order to survive. Fourthly, the area east of the city of Hue is categorized as a low valued and very low populated area. The international airport of Hue is located right in the middle of this part, about 15 kilometers east of the city. The airport is quite small, and handles approximately 800.000 passengers on a yearly basis. Furthermore, a few kilometers south of the inlet, a small harbour is situated. The main roads are located near the shoreline and just south of the lagoon. Many smaller roads are located near the city of Hue.

2.2.2 WATER DEFENCE SYSTEM

Now the land use is examined, one can look at the policy and structures in the current situation. An important step into improving the water-related system in the Thua Thien-Hue province is elaborating further on the current policy and the current water defence system. In this chapter, more information will be given on who is responsible, what is currently seen as the most important points of the system and what is done to keep the area and inhabitable as safe as possible. This chapter also gives an image of the current structures and points at some problems which were clearly visible during the fieldwork.

CURRENT POLICY

A good water management plan cannot be sustained without a good and clear policy and line of responsibility behind it. As dikes and other hydraulic structures are relatively expensive and generally won't generate profits in the form of money, no individual or company can afford to construct and maintain sufficiently safe water defences. Also, everybody behind the dike will benefit from the presence of the structure, whether the person paid for this protection or not.
Therefore, mostly governmental organizations are being appointed to issue the building and care of the water safety measures. These goods are also called merit goods. This is also the case in the Thua Thien-Hue province.

The national government issues the budget for the province to prepare and protect the lands against the threat of flooding and drought. Also, a national masterplan is in place with the main focus points of water defence and water management in Vietnam. This document, called 'The national strategy for natural disaster prevention, response and mitigation to 2020', can be seen as the backbone of the Vietnam disaster policy. This is however very superficial because of the great differences in climate and historically grown reaction to the threat of water between the different parts of Vietnam. As has been cited in other documents, this national masterplan mentions a specific strategy for the Central Vietnam region as "proactiveness in disaster prevention, and adaptation for development."(IFMP 2009)

More is done on the provincial scale. Two leading documents provide direction and guidance in the policy of water management in the region. The first one is the Thua Thien-Hue Integrated Disaster Management Plan (IDMP), elaborating further on the results from the national masterplan and the specific implementation in the Thua Thien-Hue province (MARD 2008). This plan quickly states the responsibilities of the provincial government: Flood and storm control, search and rescue and disaster mitigation within the province. The implementation and coordination of these responsibilities are administered by provincial and underlying governmental layers and advised on each layer by committees for Flood and Storm Control (FSC) and Search and Rescue (SR). This means that on each layer of government, being provincial, district and commune level, these committees are in place to advice on and coordinate the different tasks set by the national government. The chosen approach leads to a very specialised and differentiated system, which locally optimally serves the needs of the communes, but is hard to maintain in the form of a province-wide closed and optimized water management system. The IDMP analyses the system in place with the national disaster management plan in mind and develops recommendations for infrastructure, education, measurements and evacuation. Based on this analysis, the Province Action Plan has been developed with detailed actual plans for structures that have to be built in the coming years.

The second main provincial document is the Integrated Flood Management Plan (IFMP). This document is based upon both the national and provincial Disaster Management plans and tries to find an optimal solution to comply with the needs of all stakeholders involved. It tries to find the economically and socio-economically most optimizing solution with the use of structural and non-structural measures. Also a cost-benefit analysis has been made, which makes the IFMP a suitable guideline for future policymakers in the region.

FOCUS POINTS

The most abstract focus points are formulated in the before mentioned national strategy. This states that "the general goal is that of response and mitigation from now to 2020 in order to minimize the losses of human life and property, the damage of natural resources and cultural heritages, and the degradation of environment, making significant contributions to the province's sustainable development and maintenance of national defence and security."(IDMP 2010)

Although this and the before mentioned citation from the national strategy suggest a strong position for floods prevention, in reality most of the funds and attention are put into mitigation, monitoring and slowing down the degradation of the environment.

ACTUAL SYSTEM

The system in place is mainly focussed on 'coping with the consequences' instead of prevention of flooding events. A flood defence dike is in place around the lagoon at the northern and north-eastern side of the city Hue. This dike is mainly maintained by the surrounding communes, from which some crucial links are funded and coordinated by a central agency, the local dike department.

Around the Hoang River, hydraulic structures are in place to battle erosion and to steer the flow of the river. The responsibility and profits of these measures are concentrated very locally on a commune-level, making it almost impossible and economically undesirable to implement a flooding defence system along the river. Therefore, the inhabitants around the river have learned to cope with the consequences of regular flooding and adjusted their lifestyle around the currently inevitable flooding of their houses and crops. This results in limited time for harvesting during the year and large damages to buildings, where everything that cannot be moved to the upper floors will be destroyed. Each individual commune has to plan each year, based of course on district and provincial management plan and FSC & SR-advices, what the actions will be concerning the water safety and water management.

The safety of the city of Hue and surrounding communes are therefore not relying on the height and strength of the local water defences, but more on the historically chosen high position of the inner city relative to the surrounding lands and the mercy of the Huong River, where the only possible human intervention consists of the three large reservoirs upstream of the urban area, from which the third is currently still under construction. These reservoirs can be lowered before the arrival of a storm and will also be lowered before the start of the rainy season to be able to mitigate the peak discharge of the Huong River. However, the minimum discharge in combination with the huge precipitation numbers will still cause yearly flooding, making larger and more measures necessary.

The current water defence system is therefore inadequate in defending important infrastructure and urban areas, where the possibility of flooding is totally random once the water rises, not depending on whether the area is uninhabited agricultural land or a high-value urban area, but only depending on the height of the lands and the path of the storm. The possibility of an economically superior water management plan, where distinction is made between what is valuable and what is not and where all different functions of the river are mentioned and considered, is certainly worth further investigation.

To get an impression of the current situation along the Huong River some pictures are made of the current protection against the water during the fieldwork (see appendix B). The pictures are shown in Figure 13 and Figure 14. From Figure 13 one can conclude that there are no dikes along the river to protect the people for flooding. The houses are built very near the riverside, especially in the city of Hue and more downstream of the city, this makes it impossible to build a dike along the riverside without large scale relocation of the people. More upstream of the city of Hue, the lands change to a more mountainous and less populated area and more room is available for creating a dike along the river.

Some riverbanks are already protected by concrete (picture 5 of Figure 13), stones (picture 8 of Figure 13) or gabions (picture 6 of Figure 13). But overall, the riverbanks along the Huong River are mostly not protected against erosion. During the fieldwork a lot of eroded riverbanks were spotted, for example picture 3 and 4 of Figure 13 show riverbanks where erosion was clearly visible. The riverbanks must be protected against erosion in the densely populated areas, otherwise the river will move inland which can harm or even destroy the houses that are located along the riverside or bridges. In those areas one would like to have riverbanks in which the location remains the same, so more attention should be paid to the protection of the riverbanks in the densely populated areas. Figure 12 and Figure 15 are some pictures where the erosion is clearly visible. Figure 15 is taken a month after the flood of 2013. The sandbags are still located in front of the garden. One can see that due the flood a lot of soil was eroded under the stairs and along the wall.

FIGURE 12: A RIVERBANK THAT IS VERY SENISTIVE TO EROSION

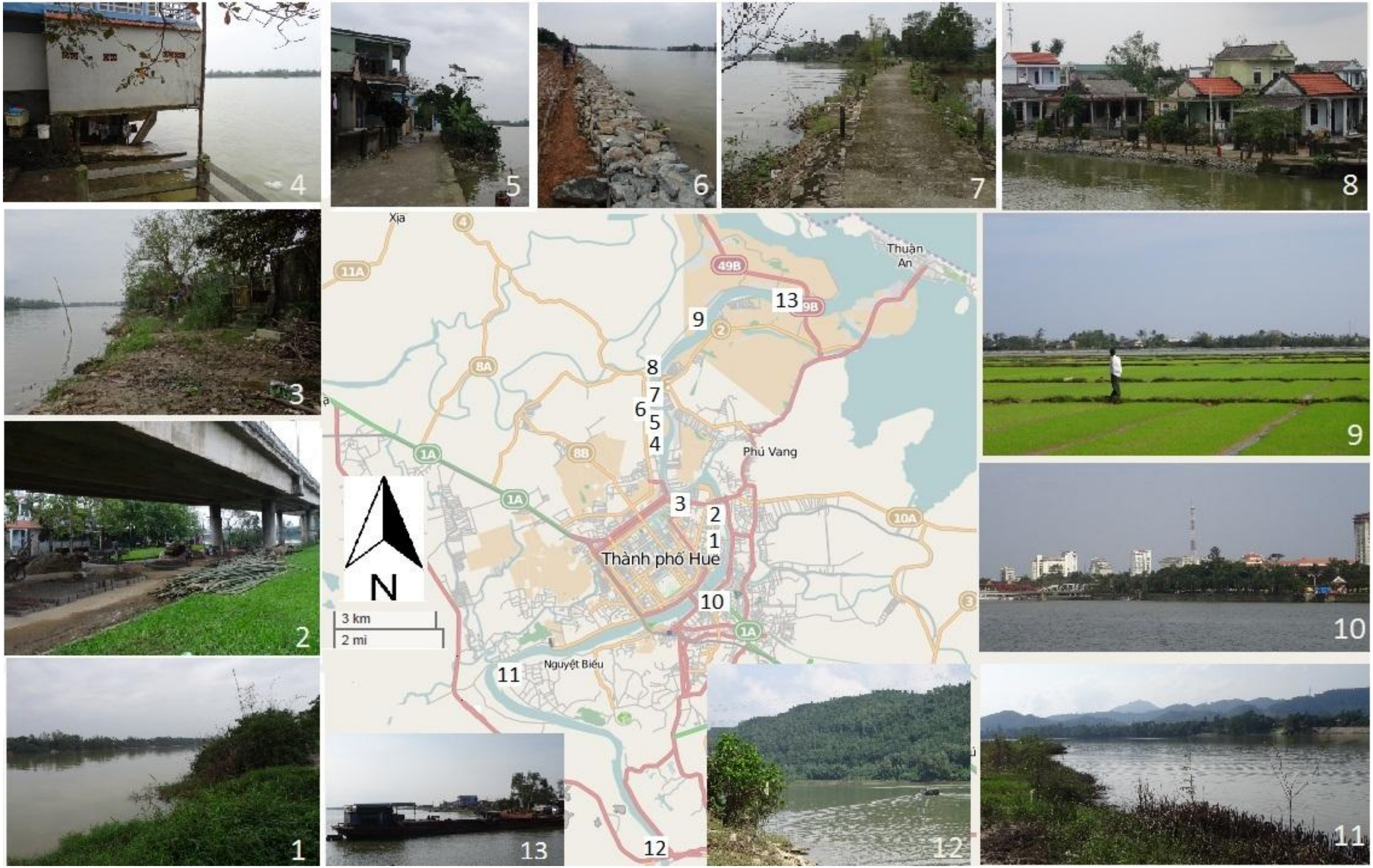


FIGURE 13: RIVERBEDS ALONG THE HUONG RIVER, PHOTOS ARE TAKEN DURING THE FIELDWORK IN DECEMBER 2013

FIGURE 15: EROSION ALONG THE WALL (YELLOW) AND UNDER THE STAIRS (RED) ALSO SANDBAGS ARE STILL LOCATED IN FRONT OF THE GARDEN (GREEN)

In Figure 14 the outlets and the main construction in the coastal plain are shown. In picture 1 of this figure one can see a weir. This weir can be closed when the water in the Huong River is too high. This will protect the lower located area behind the weir from flooding. This area is called Phu Vang and has to deal with a lot of flooding each year.

In picture 3 and 6 of Figure 14, one can see the two outlets. Only through these two outlets all the water from the 3 waterbasins with a total area of approximate 2000 square kilometer must flow to leave the coastal plain.

Picture 2 of Figure 14 shows a weir that is located at the downstream part of the Huong River. This weir closes when the discharge from the Huong River is low, to minimize the salt intrusion from the sea. Picture 4 and 5 Figure 14 of the Truoi Reservoir is shown. In the province there are 3 reservoirs. Truoi is the smallest reservoir. The other two reservoirs are the Ta Trach and the Binh Dien reservoirs and located upstream of the Huong River. Those reservoirs are recently built to protect the people against flood and drought.

FIGURE 14: OUTLETS AND CONSTUCTIONS IN THE COASTAL AREA OF THE THUA THIEN-HUE PROVINCE, PHOTOS ARE TAKEN DURING THE FIELDWORK IN DECEMBER 2014

2.2.3 FLOODS IN THE THUA THIEN-HUE PROVINCE

TYPE OF FLOODS IN THE THUA THIEN-HUE PROVINCE

The fluvial floods in the Thua Thien-Hue province can be subdivided into four different types (Shaw and Sonak 2006): First, the main winter floods, occurring from the month of October to December, which often reach a great magnitude, lasting long with very high peaks. Secondly, the late floods that occur at the end of December and never exceed the dangerous flood conditions. Thirdly, the early floods which occur mainly during May to June; these are floods that have a short lasting time. Fourthly, the summer floods, occurring from mid-July to mid-September, have moderate peaks and magnitude.
These different types of floods are important when one looks at the water damage. For the farmers the main winter floods occur during the end of the farming season, so the farmers can prepare for the floods and harvest their crops quickly. However, the severe floods have consequences reaching further than harvests alone. They occur suddenly, overwhelming the local people's ability to take precautions to minimize the damages. For the farmers summer floods are considered more as a hazard because they often occur during the growing season and will destroy the crops of the farmers.

1999 FLOOD TESTED WITH THE CURRENT SITUATION

The recent years the Thua Thien-Hue province suffered from numerous floods, ranging from floods with enormous damage and loss of live, to yearly floods that people are accustomed to. The government of Vietnam has made a disaster plan and has built some structures to protect the lands from flooding. Sadly, floods still occur frequently. One of the protection measures taken are the construction of two reservoirs named the Ta Trach- and the Binh Dien Reservoir, upstream from the city of Hue. In Figure 16 and Figure 17 the 1999 flood is simulated in Mike (coupled mike11-mike21) with and without the reservoirs. From this can be concluded that the area is still flooded in the case with reservoirs, but to a lesser extent (Hoai, Bay et al. 2011).

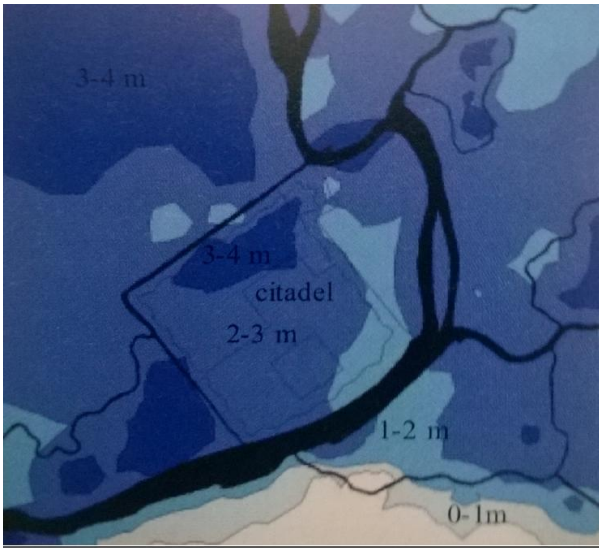


FIGURE 16: THE MAXIMUM FLOOD DEPTH IN HUE CITY AND CITADEL WITHOUT THE TA TRACH- AND BINH DIEN RESERVOIRS (HOAI, BAY ET AL. 2011)

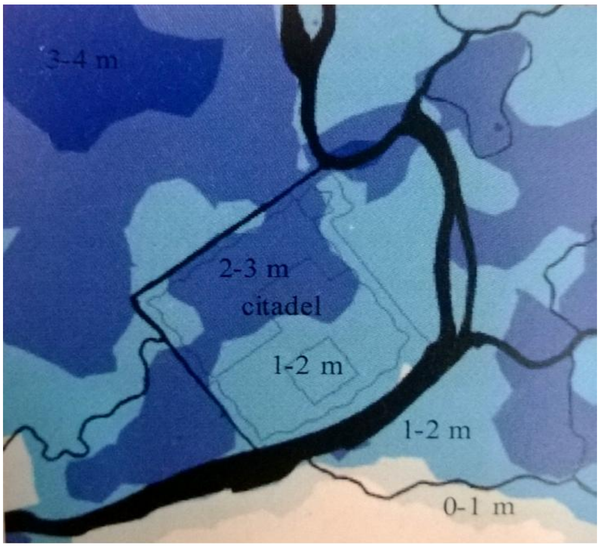


FIGURE 17: THE MAXIMUM FLOOD DEPTH IN HUE CITY AND CITADEL WITH THE TA TRACH- AND BINH DIEN RESERVOIRS (HOAI, BAY ET AL. 2011)

The measures taken by the government have already had some positive impact on the flooding, but there is still a lot of water nuisance in the city. Also the making of a disaster plan will improve the safety of the people.

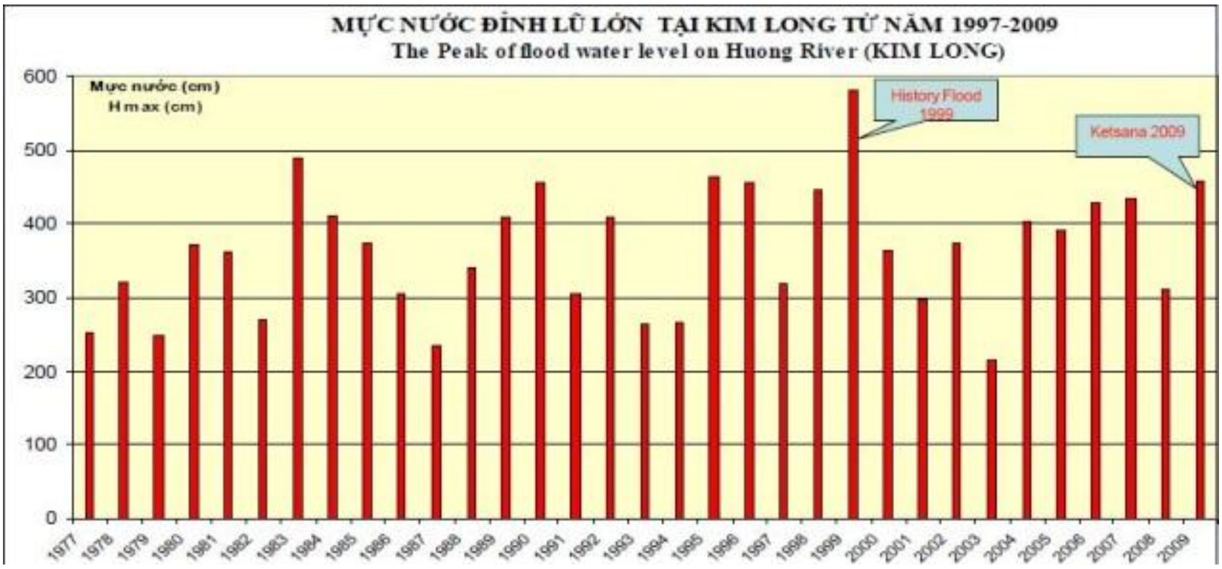


FIGURE 18: PEAK OF FLOOD WATER LEVEL ON HUONG RIVER (KIM LONG STATION) (THANH)

2.2.4 RETURN PERIODS OF THE FLOODS

Maps showing the extent of the flooding in the province and data on the discharge of the Huong River give the opportunity to classify the floods in recent history with a return period. Using the water levels in the Huong River at the Kim Long measuring station during floods, shown in Figure 18, one can estimate the return period. A flood with a certain return period can be used as input for the SOBEK model.

ONCE IN FIVE YEAR FLOOD – THE FLOODS OF 2007 AND 2013

The most recent flood, in November 2013, is not shown in Figure 18. A consulting expert, Dr. Mai Van Cong estimated the return period of this flood as a once in five years flood. Another flood, also with a return period of roughly 5 years, is the flood of 2007. During this flood, the water level in the Huong River rose to approximately 4.3 meters. Since only a couple of weeks have passed since the 2013 flood, there is no readily available flood map yet. Signs of the 2013 flood will still be visible though, making observations in the field possible to determine water levels in inundated areas. Taking all this into account, it is possible to use both the 2007 and 2013 flood to create a complete image of a once in five year flood, while keeping an eye out for differences between the floods.

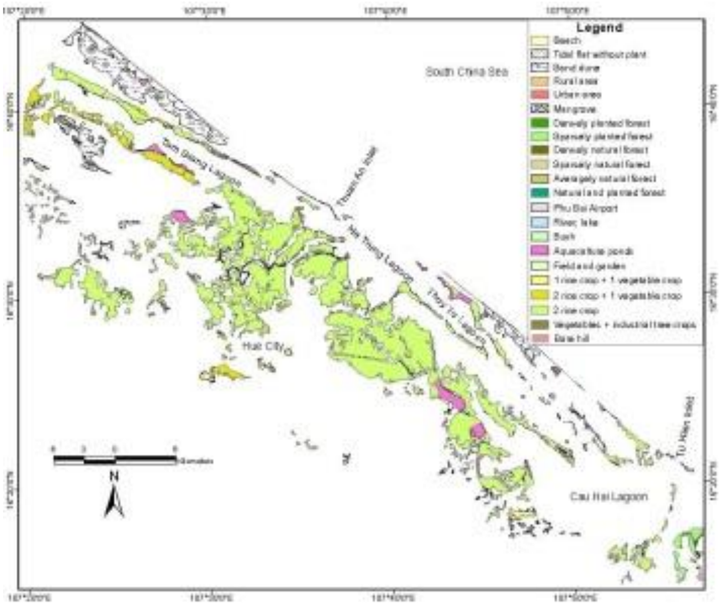


FIGURE 19: FLOODING OF THE THUA THIEN-HUE PROVINCE IN 2007 (LAN AND VAN THAO 2011)

The extent of the flooding in 2007 is shown in Figure 19. The following can be concluded: First, the area between the city of Hue and the lagoon is for the largest part inundated, as well as large sections along the lagoon to the North and South. Secondly, the old centre of Hue and land with some distance from the coast is not flooded according to this map.

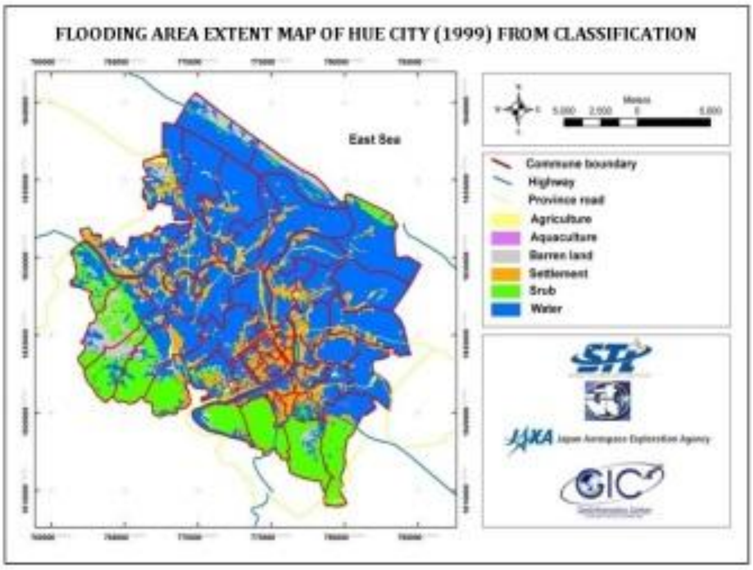


FIGURE 21: FLOODING OF CITY HUE IN NOVEMBER 1999 (VILLEGAS 2004)

ONCE IN A HUNDRED YEAR FLOOD – THE FLOODING OF 1999

When larger floods are investigated, like the historical flood of early November 1999, one sees a similar picture, but with flooding on a larger scale. Figure 20 and Figure 21 show the flooding due to the extreme event that took place in early November 1999 in the city of Hue and the Thua Thien-Hue province respectively. The water level in the Huong River reached 5.81 meters above mean sea level at the Kim Long measuring station, causing flooding in the majority of the coastal zone in the province. The flood map of the city of Hue shows that parts of the old city centre were flooded, but some sections still remained dry. The flooding of 1999 is the most extreme event that has been recorded, making it a once in 100 year flood event with the current records. Figure 22 and Figure 23 show the water level north east of Hue city. The depth of water above the ground level was more than 2 meter in many areas. 90% of the lowlands was flooded.

FIGURE 20: FLOODING OF THE THUA THIEN-HUE PROVINCE ON THE 6TH OF NOVEMBER, 1999 (VILLEGAS 2004)

FIGURE 22: LOCAL SHOWING THE HEIGHT OF THE WATER DURING THE FLOOD OF 1999 (PICTURE TAKEN DURING THE FIELDTRIP)

FIGURE 23: A LANDMARK OF THE FLOODING IN 1999 (PICTURE TAKEN DURING THE FIELDTRIP)

ONCE IN TWO OR FIFTY YEAR FLOOD

Determining the extents and conditions during a once in 2 year flood, as well as the once in 50 year flood is a little less straight forward than the return periods described earlier. The other floods in the record do not seem to have the once in 2 or 50 year return period. A rough estimate can be made for the water level in the Huong River, matching a once in 2 or 50 year flood with the record shown in Figure 18. Figure 24 shows the different floods and their return periods. The water level data is received from the Kim Long Measuring Station and is also shown in Figure 18. A continuous logarithmic trend line can be plotted through this data to estimate the water level in the Huong River during a once in 50 years flood. The resulting flood extents can be obtained through modelling with a 2D overland flow model.

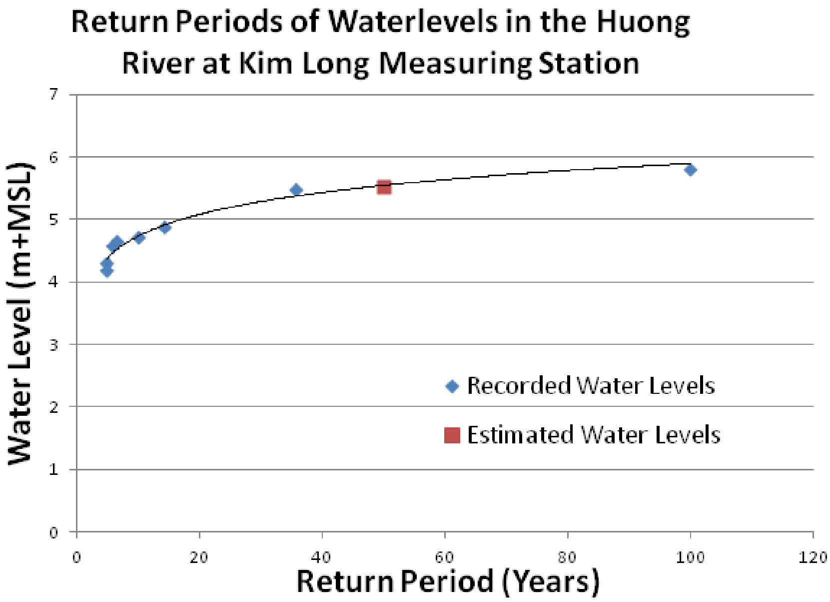


FIGURE 24: RETURN PERIODS OF WATERLEVELS IN THE HUONG RIVER AT KIM LONG MEASURING STATION

2.2.5 THE SOBEK MODEL

Modelling the flood plain of the coastal zone of the Thua Thien-Hue area gives the advantage that the consequences of any changes in the area can be evaluated. SOBEK is the program that is used in this case, containing a 1 dimensional network with rivers, canals and structures, and a 2 dimensional grid to model the overland flow. Interaction between the two modules results in an estimation of the inundation depth and flow velocities of land. Such a model as this is a powerful tool but needs to be used carefully. Many simplifications cause the outcomes to differ from reality. Determining where and how these differences occur, where the model is not reliable and where the results are closely related to reality is needed to be able to correctly interpret the results.

Building an intricate model containing detailed cross-sections, bed levels and surface levels is very labour intensive and does not contribute to this project. This is the reason why a consulting expert, Dr. Nghiem Tien Lam, has been found willing to supply us with a working model of the area. This model, build in 2005, contains cross-sections for most of the streams, as well as a 2D elevation grid for the flood prone area. The boundaries in the model are the South China Sea, the Bo River, the North West end of the Tam Giang lagoon, the Huu Trach and the Ta Trach River. The input for these boundaries is supplied together with the model for the period of the flooding in early November 1999. Both the discharge of the rivers and sea water levels at that time are thus known. The schematization of the model is shown in Figure 25.

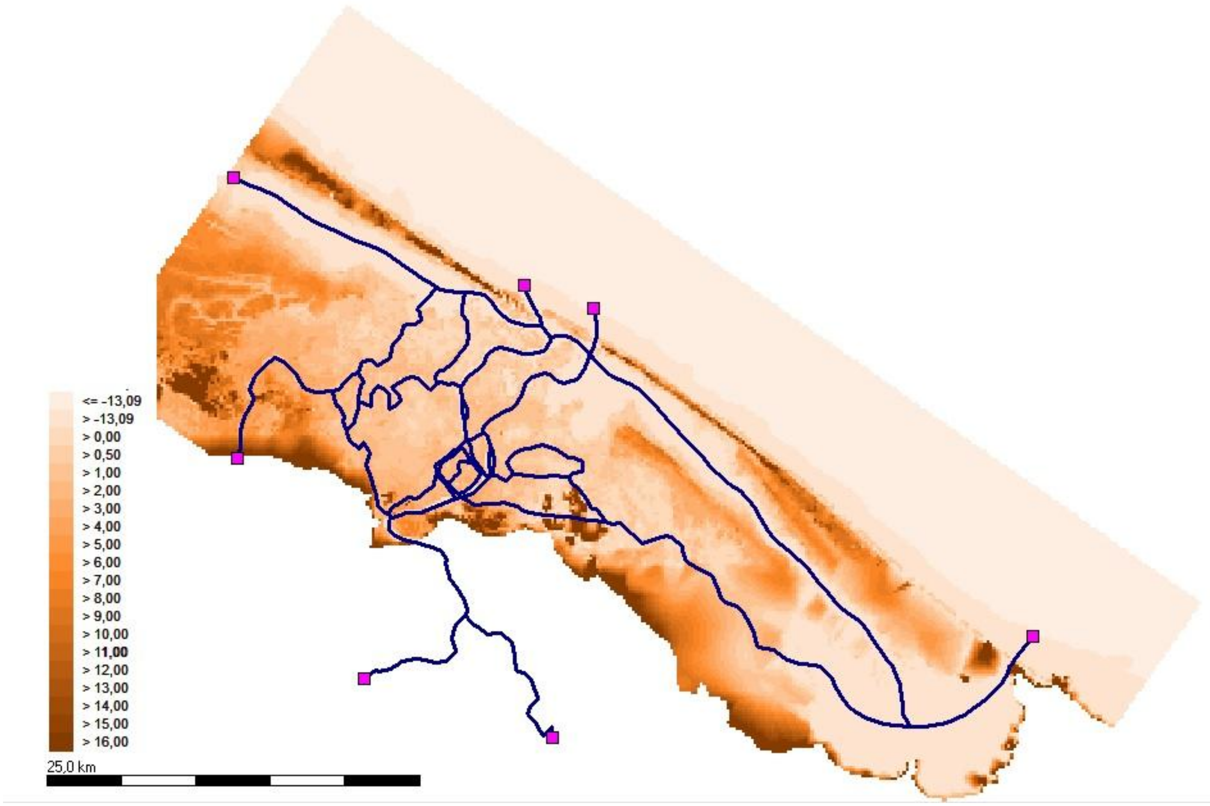


FIGURE 25: THE SCHEMATIZATION OF THE SOBEK MODEL

FIGURE 26: SCALE SHOWING THE FLOOD LEVELS

VALIDATING THE MODEL

Validating the model is in the first case done by comparing the flooded areas in the SOBEK model with records of the actual flooding events. This will primarily be done for the flooding of 1999, as more detailed flooding maps and water levels are available there.

FLOODING OF 1999

The flooding simulated with the SOBEK model is shown in Figure 27. The flooded areas, at the peak of the flooding, show big similarities with the flood maps discussed previously. Differences occur in the city centre, were the flood maps show some areas that are not flooded while the entire city centre floods in the model.

Places where the flood levels are known through observations of local people and water level poles confirm the water levels from the model to a great extent. The scale shown in Figure 26 shows a water level of approximately 3.05 meters above datum. The model shows a maximum water level of 3.2 meters at the same location. The guide in Figure 22 shows how high the water level reached during the same flood, near his house. The visually estimated height above the water level at the time that the picture was taken is roughly 3.5 meters.

Water levels in the Huong River are measured on several locations. The most interesting one is the Kim Long measuring station located near the Hue Citadel. The measurements during past floods allow for comparison between reality and the model used in this study.

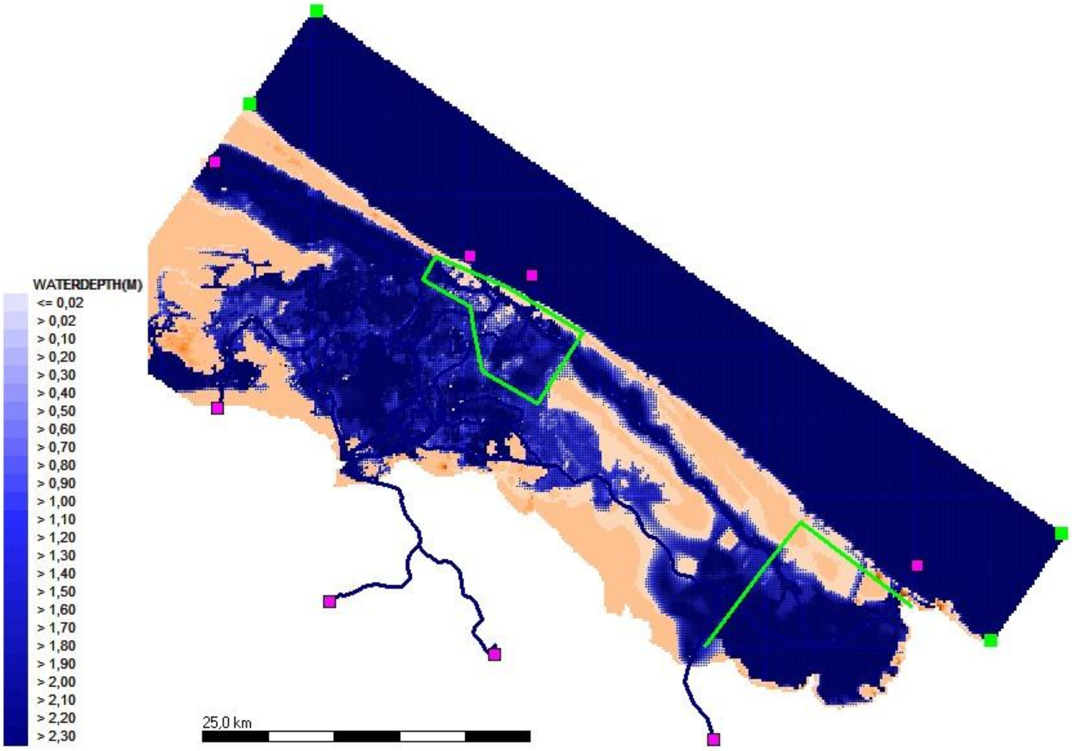


FIGURE 27: THE FLOODING IN 1999 AS MODELLED IN SOBEK

The water level in the Huong River reached a maximum of 5.81 meters during the flood of November 1999. The modelled water level of this flood on the same location is shown in Figure 28. It resembles the maximum value of the water level in the river closely.

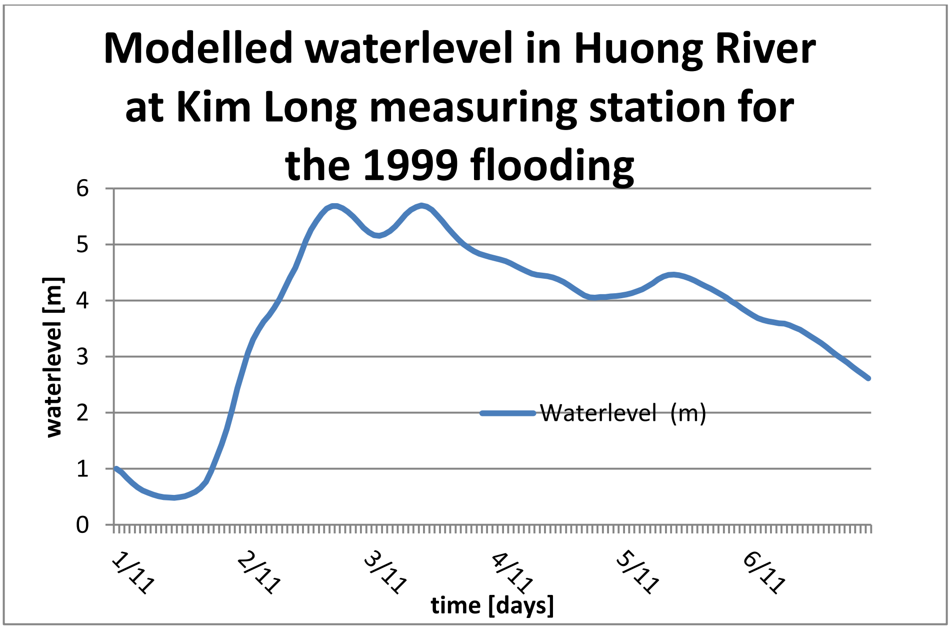


FIGURE 28: MODELLED WATERLEVEL IN THE HUONG RIVER AT KIM LONG MEASURING STATION FOR THE 1999 FLOODING

FIGURE 29: WATER LEVEL DURING THE FLOOD OF 1999

FIGURE 30: WATER LEVEL DURING THE FLOOD OF 1995

FLOODING WITH A RETURN PERIOD OF APPROXIMATELY 5 YEARS

The flooding in November 2007 has a return period of approximately 5 years. Recreating this flooding in SOBEK allows us to adapt the system to this magnitude of flooding. The basis of this model is the once in 100 year flood based on the event in November 1999. The rainfall in the model has been reduced to lower the water levels in the Huong River to the levels found in 2007. The water level in the Huong River, that reached 5.81 meters in 1999, now reaches 4.3 meters according to measurements done during the flooding. The SOBEK model shows a close resemblance as can be seen in Figure 31.

The modelled water level near the gauge shown in Figure 29 reaches just over 2 meter above mean sea level. This is similar to the water level during the flood of 1995 shown in Figure 30. The flooding of 1995 has a return period of 6.7 years. This indicates that the model overestimates the flooding at that point a bit, but still gives a relatively good representation of a once in 5 year flooding.

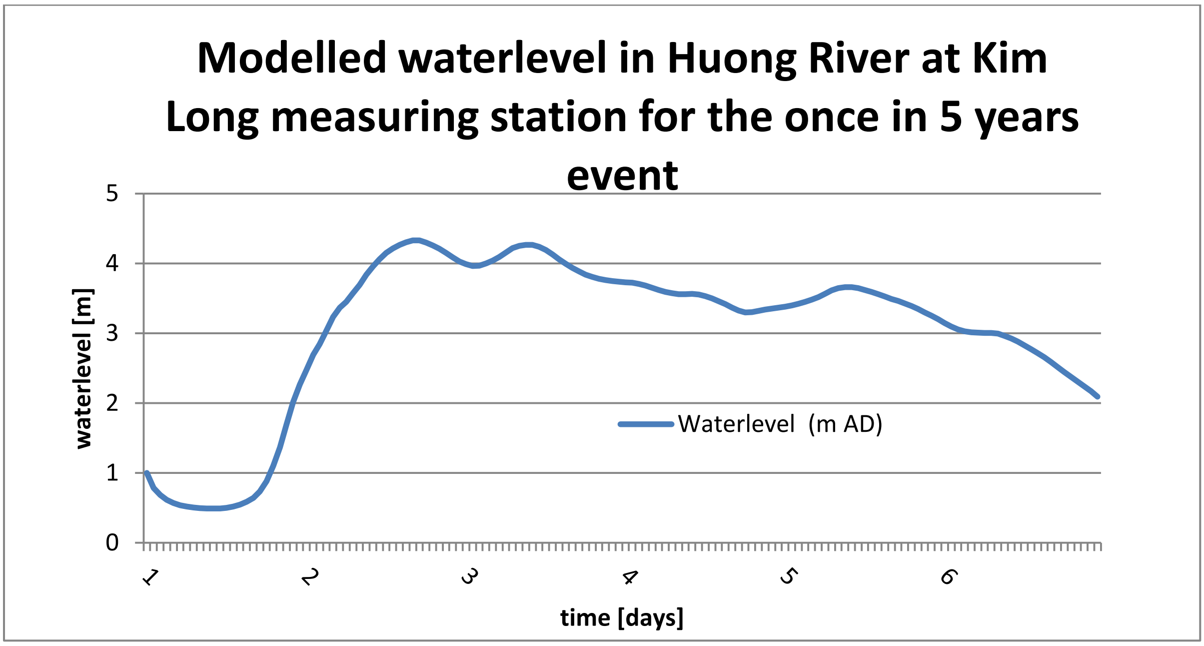


FIGURE 31: WATER LEVEL IN THE HUONG RIVER AT THE KIM LONG MEASURING STATION FOR THE ONCE IN 5 YEAR SIMULATED EVENT

FLOOD PROGRESSION

Flooding occurs in the area due to a number of factors. Rainfall and river discharge provide the water and a number of bottle necks in the area cause the lands to flood. Flooding starts on several locations upstream from a bottle neck and travels overland to other areas. Figure 32 through Figure 35 show the progression of flooding during the simulated flood of once in 5 years. Flooding occurs first at the mouth of the Bo River, moving upstream with time. In the upstream region of the Bo River, flooding occurs because of a bottle neck. The flooding caused by the bottle neck in the upstream region starts to propagate over land in a northern direction towards lower areas.

The Huong River appears to flood at several locations where the discharge exceeds the capacity. A backwater curve is created which floods upstream areas. At this time, the flooding from the mouth of the Bo River, at the estuary, has travelled a significant distance upstream. Also, the Huong River starts flooding areas near bottle necks both up- and downstream of the city of Hue.

The flooding continues to expand and soon covers large portions of the area. Several dark spots can be distinguished implying high inundation depths.

Finally, the flood propagates to the south east, covering even more surface area with water.

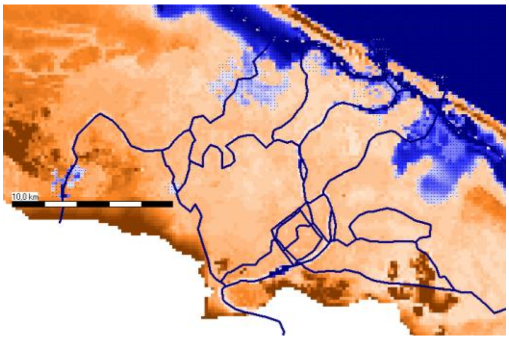


FIGURE 32: 1-THE PROGRESSION OF FLOODING DURING THE SIMULATED FLOOD OF ONCE IN 5 YEARS

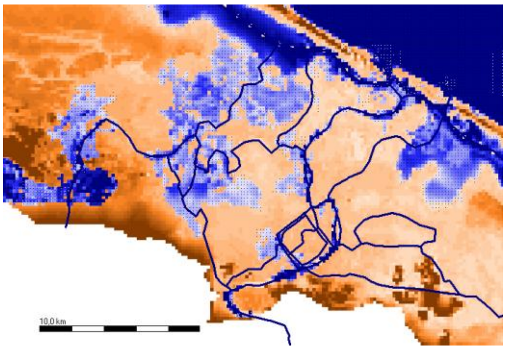


FIGURE 33: 2-THE PROGRESSION OF FLOODING DURING THE SIMULATED FLOOD OF ONCE IN 5 YEARS

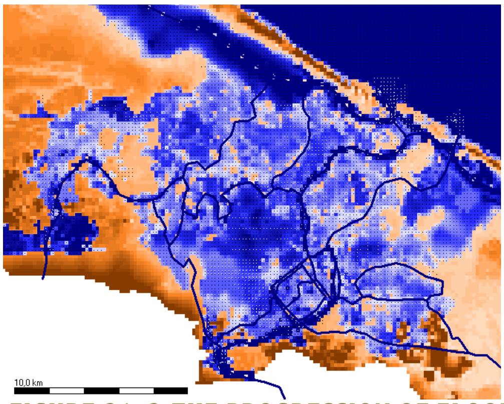


FIGURE 34: 3-THE PROGRESSION OF FLOODING DURING THE SIMULATED FLOOD OF ONCE IN 5 YEARS

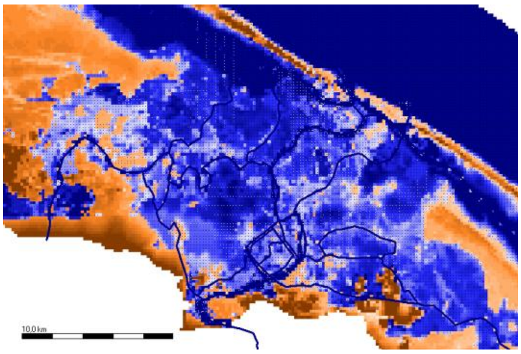


FIGURE 35: 4-THE PROGRESSION OF FLOODING DURING THE SIMULATED FLOOD OF ONCE IN 5 YEARS

CAPACITY OF THE HUONG RIVER ACCORDING TO THE SOBEK MODEL

So far, the SOBEK model has been used to look at the flooding. But the capacity of the biggest river in the area gives valuable information on where any solutions need to lead to. An iterative process to estimate the largest discharge that does not result in flooding from the Huong River has resulted in a value of 600m^3/s. This value will be used as a guideline when the flows in different streams are chosen and evaluated.

DIFFERENCES BETWEEN THE MODEL AND REALITY

The SOBEK does not give a realistic representation of the real world on every level. The flooding during a once in 5 year storm, as described above, shows significant flooding in and around the city centre of Hue. This area did in reality not flood during for example the flooding of 2007, even though the water level at that same location in the river is very close to the measured value. Possible reasons for these differences are the absence of the urban drainage network in the model and inaccuracies in the digital elevation model due to its relatively coarse resolution.

However, another big difference between the actual flood and this model seems to be the duration of the flood. The model shows that large portions of the land surface are still inundated after several days. In reality, the flood did not last this long. This limits the conclusions that can be made about the length of the flooding and should also be considered in other cases, such as the flooding of 1999.

2.3 APPLYING THE FRAMEWORK FOR INTEGRATED WATER MANAGEMENT TO THE THUA THIEN-HUE PROVINCE

In this section, first the desired return periods will be shown. This map is made with the use of the land use map. Then the operational prevention measures against flooding and drought will be discussed, because making structures alone is most of the time not enough or inefficient to prevent the land for flooding and drought. When these operational prevention measures are discussed, the structures will be discussed. First, some reference structures are shown as possible solutions. These reference structures are kept in mind when discussing possible structures for improving the water problems in the Thua Thien-Hue province. In the last part of the chapter, these possible improvements will be combined into some promising combinations, which can be tested in the following chapter.

2.3.1 DESIRED SITUATION

The desired situation would result in a map in which subareas are divided in different return periods for floods. This is also the main goal to achieve when making the structures against flooding. The area must have the safety of the return period shown in this map; otherwise extra protection measures must be taken to comply with the goals set by the Framework for Integrated Water Management.

DESIRED RETURN PERIODS

The whole project area has been divided into several subareas in order to be able to allocate the level of safety for each subarea in an economically attractive way. The boundaries of an individual subarea consist of rivers and/or dikes. Within an individual subarea its value has been estimated to find a suitable return period of a flooding. The value of each subarea has been investigated in a qualitative way.

Water consulting expert Mai Van Cong has done some research on the desired return periods for the different land uses. These proposed return periods are taken as a starting point for the first design of the area. There are however some adjustments made. Opposite to the approach of Dr. Mai Van, no distinction has been made between high valued crops and low valued crops. During the site visit in Hue it turned out that the areas which were supposed to be high valued crops did not show significant differences to the low valued crops. A second difference is the addition of the category aquaculture, which is given a desired return period of 2 years. This return period is based on the estimated value on the one hand and on the other hand the measurements which have to be taken in order to protect these shrimp farms. The different return periods are given in Table 5:

TABLE 5: THE DIFFERENT RETURN PERIODS FOR THE DIFFERENT LAND USAGE IN THE THUA THIEN-HUE PROVINCE

Type of land	Feature	Desired return period
Urban area	High population density	100 years
	Average population density	50 years
Non-urban area	Small villages	5 years
	Agricultural land	2 years
	Aquaculture	2 years

The resulting map with the different subareas including the desired return periods are shown in Figure 36.

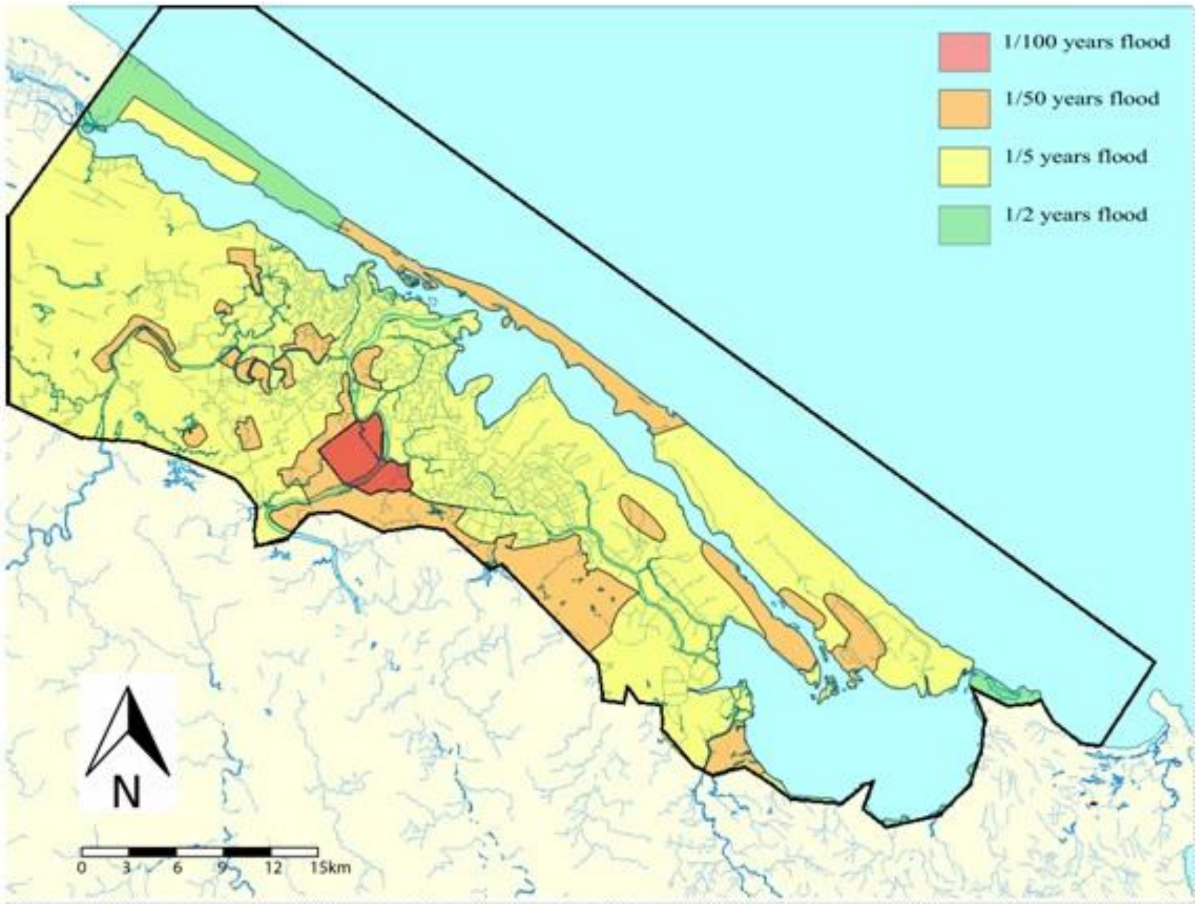


FIGURE 36: THE DESIRED RETURN PERIOD FOR THE COASTAL PLAIN OF THE THUA THIEN-HUE PROVINCE

2.3.2 POSSIBLE SOLUTIONS FOR THE PREVENTION AGAINST FLOODING AND DROUGHT

Management of many different factors in the area is a valuable measure against flooding, besides the structural measures discussed after this section. Controlling the allocation of surplus or deficit of water within the Thua Thien-Hue province can reduce the consequences of flooding a great deal. Creating an adequate management scheme is a challenge due to the many different aspects that influence the system and different demands required of the system. Some examples of these aspects are the influences of the river run off, sea water levels and rainfall on the amount of water in the system. These can in turn be influenced by the management of reservoirs and control structures. And this is affected by actions of people in the area by for example good or bad maintenance, water use and conflicting interests between users. Each of these influential aspects needs to be taken into account when designing the water management system.

OPERATIONAL WATER MANAGEMENT: RESERVOIRS AND CONTROL STRUCTURES

Various reservoirs, located in the mountainous region of the province, provide the possibility to store water when water is plenty and discharge the stored water in times of shortage. The rules set to the operational management of each reservoir depend on the capacity and purpose of the reservoir. A reservoir designed for the production of hydro-electric power will function in a different way than a reservoir purpose build for storage of water. The ranking of the different functions of the reservoir in question determines the boundaries in the system, where the secondary objectives of the reservoir are optimized within the boundaries. For example, a hydro-electric dam is ideally used to prevent large scale damage due to flooding in the first place trough storing water during heavy rainfall. But besides that, it aims to use the available potential energy with the highest efficiency.
The operational control of the control structures in the area is a powerful tool in managing the water recourses in the area. It gives the water managers the option to route water through lower populated areas while avoiding densely populated areas. During droughts, it can supply the available water to areas that need it the most, while cutting off supply to areas with less need for water.

WATER RETENTION AND STORAGE

Reservoirs are not the only areas that can be used to store water. Areas with a low population density and a comparatively low economic value can be used to catch and retain water to reduce the peak discharge in the large rivers. This reduces the flood levels in other areas. The suitability of a specific area for water retention depends on multiple factors. The first is the geographic location. Using an area for water retention upstream is straight forward as the flow towards the downstream areas can be restricted, inundating the upstream area on purpose. This is similar to building a reservoir, with the difference that the water retention area is only inundated when flooding of the downstream area is likely. Creating a water retention area downstream of the valuable land is also possible, but the capacity of the river needs to be high enough to route the water to the area. Inundating the downstream area will keep the water level in the river low enough to ensure a sufficiently large discharge.
Another aspect that is of significant importance is the elevation of the terrain. The elevation determines the bounds of the inundated area. It can be changed by building levies, but this can be costly on a large scale. The elevation of the area also determines the possibilities of draining the area after the peak of the flood. This allows the land to be used for its primary purpose as fast as possible.
Water storage with the purpose of reducing the effects of droughts is done in the form of reservoirs. These reservoirs can be either big or small. Big reservoirs are more efficient and allow for production of hydro-electric power, but need a big investment. Small reservoirs can be built almost anywhere, ranging from a water tank filled by rainwater to larger basins connected

to the main stream in the area. Smaller storage facilities can be controlled by the local owner, with oversight from governmental agencies, increasing the benefits for the owners and making the investments worthwhile.

DRAINAGE

Good drainage facilities, primarily in urban areas, offer the opportunity of discharging excess rainwater efficiently and reducing the direct effect of this rainwater. Urban areas have a large percentage of paved, impermeable surfaces. This causes the water to runoff to the surface water, or pond on the streets, creating flooding. The drainage facilities can collect the water and discharge it out of the system. Although the water can cause flooding somewhere else, it is more desirable than flooding of densely populated area where the chances of loss of life are larger.
Drainage systems of rural areas have the same function as their urban counterparts, but have different characteristics. They are less crucial as the water also has the possibility of infiltrating into the ground and running of that way. Having a decent drainage system in rural areas allows inundated areas to drain faster, allowing for faster reuse of the land and less economic damage. Drainage of inundated lands is limited by any levies surrounding the land, trapping water inside. If levies are used to protect land against flooding, control structures can be integrated into the levy system to allow sufficient drainage capacity.

MANAGING SALT INTRUSION

Salt intrusion from the sea along the rivers can cause problems by damaging crops. Salt intrusion is only a problem when the discharge in the river is low, during the dry season. Salt intrusion can be limited by cutting the sea off from the fresh water bodies, but this is not desirable as some areas need brackish water for aquaculture, like the lagoon in the Thua Thien-Hue province. Salt intrusion can be controlled from either the downstream end or the upstream end. Downstream control of salt intrusion is done by limiting the cross-sectional area of the stream during the dry season. Gates or sluices allow for water to flow through almost unrestrained during the wet season while limiting flow from the sea to the fresh water bodies during dry season. Upstream management of salt intrusion can be done by creating a sufficient discharge in the river. This pushes the salt water back into the sea.

2.3.3 POSSIBILITIES IN WATER DEFENCE SYSTEMS

To prevent areas from flooding, measures have to be taken to protect such areas from high water levels. There are three groups with solutions. On one side a solution can prevent water flowing from river over land. In this group, one has to think of constructions like a dike built out of soil along the riverbanks. Secondly, a construction can prevent water flowing through the river on specific location and time, for example with the use of a weir. A third group consists of measures that prevent seawater flowing in to the river, for example at high tides or in special cases when a tsunami or typhoon occurs.

PREVENT WATER FLOWING OUT OF THE RIVER

This can be done with many different structures, which will be discussed below. It mainly consists of permanent or temporary retaining structures.

DIKES

As mentioned in the introduction, solutions can prevent water flowing out of the river over the land. A frequent used solution is building dikes made out of soil along rivers, channels, estuaries and seas.

A benefit of building dikes is that it provides a relatively cheap solution. Soil is available almost anywhere and excavators are easily obtainable. Apart from the benefits, dikes do also have some major disadvantages. For example, the dikes require a lot of space. In cases where buildings are built directly along the riverside these buildings have to be removed first or the width of the river has to be adapted. Both solutions are very costly and usually receive strong resistance from local people and political parties. There is also another major disadvantage of building dikes, where in times of floods the water level in the river will rise. In the current situation, water will flow both over land and through the river. When one prevents water flowing over the land the water level in the river will become even higher. This implies that dikes have to be heightened to even higher retaining levels. This also requires even more space between the riverbanks and current available buildings.

CONCRETE WALL/SHEET PILES

To minimize the horizontal required space also concrete walls or sheet piles can be placed. Also this solution has the disadvantage of an increasing water level in the river. Preventing water flowing overland means that this water has to flow to the river, what in turn results in further increasing of the water levels. Although the horizontal required space decreases, this solution is very costly. Concrete and/or steel must be available and such kind of vertical walls ensure that local inhabitants cannot reach the river anymore for their daily affairs like fishing or washing clothes. For this problem gaps or doors can be created but these constructions increase the chance of errors, with floods occurring as a result after all. Also, when considering touristic attractiveness, this will not provide the most attractive solution. The beautiful view along the riverside is gone and replaces by the concrete or steel wall.

MOBILE PROTECTION SYSTEM AGAINST FLOODS

To make use of the benefits of sheet piles but to avoid the disadvantages, a mobile protection system against floods can be used, as can be seen in Figure 37. The idea behind a mobile protection system is that it is deployed in case of high water levels and threatening floods. In those cases temporary components can be placed between already installed holders. These components can be removed afterwards.
Benefit of this solution is that it can be installed in places where there is little space available. Also, people are free to move in normal cases of low water levels from their houses to the riverside for example for washing or sailing. Big disadvantage is that it will be even more expensive than a concrete wall or sheet pile solution. Also all components have to be installed in order to prevent floods. One incorrectly placed or missing component can flood the area. An installation plan has to be developed in order to prevent such mistakes and a maintenance plan has to be created in order to hold the mobile protection system in good condition. Besides this, these plans will be costly and implementation is labour intensive.

FIGURE 37: MOBILE PROTECTION SYSTEM IN USE IN GERMANY (RUNDFUNK 2013)

PREVENT WATER FLOWING THROUGH THE RIVER

The second form of solution does not react on the consequences but tries to prevent the cause of the problems in the city of Hue. These mainly consist of individual but large scale structures.

FLOOD STORAGE AREA

In order to prevent some areas from flooding, other areas upstream can be sacrificed and used to store the water. If one want to protect the city of Hue, for example an area upstream of the city can be flooded on purpose in order to prevent the water flowing immediately downstream. When the water level in the river becomes lower, the stored water can flow to the sea. With use of flood storage areas, the flood peaks can be smoothened in order to minimize the problems in areas with a high economic value or a densely populated area.

There are a lot of benefits from the solution mentioned above. When water levels do not increase significantly anymore as a result of the mitigation of the flood peak, there is no need to build other water retaining structures along the riverside downstream of the flood storage area. Especially for places where houses are built directly along the riverside the solution of a flood storage area can be very useful.

Disadvantages of the solution above consist again of the costs of preparing a region as flood storage area. An inlet has to be created to let the water flow in the area. On the other side of the storage area dikes have to be built to prevent water flowing directly overland to neighbouring areas. Lastly, as probably the most important disadvantage, a lot of people live in the project area. Because the possible locations of a flood storage area are minimal due to elevation patterns, it is hard to find an area which has no population. The result of this is that people are currently living in areas that can be appointed as future flood storage areas and have to move to prevent their houses and belongings to flood considerably more often.

RESERVOIR MANAGEMENT

Instead of creating a new flood storage area, already existing reservoirs can be used to prevent flooding. In times of high precipitation dams can be closed in order to control the discharge in the river. Also, the storage capacity can be increased by releasing water when a heavy rain event is forecasted. The volume of the reservoir has to be sufficient to store all rainfall water. In dry times water can be used for irrigation to compensate the lack of water during those months. It is depending on the size of the reservoir if this solution is suitable. On the other side, a lot of precipitation can fall downstream of the reservoir, resulting in flooding after all. There are also some contradicting interests when using reservoirs and their dams for flood protection. Almost all reservoirs are built with the purpose of creating electricity using waterpower. When a dam is closed for several days or weeks, no electrical power will be generated. Since most of the dam owners are public investment companies, they will have different interests as the policy makers of the government.

BYPASS

Another possibility in order to lower the water level in the river is creating a bypass so water can flow along another path to the sea. The bypass is only used when the discharge of the river becomes critical downstream. The bypass will be used to transport the extra amount of water through an additional temporary river. Costs for this solution are very dependent on the size and length of a bypass channel. Very small quantities can be transported by use of pipelines however major quantities have to be transported by use of channels. Also the elevation of the land is of major influence. Because water will always flow downwards, a water flow path must be found from a point upstream of the area which has to be protected to a point downstream where the bypass system can join the original river or can flow directly to the sea. Also for this option people living in the new route of the bypass system have to be relocated, which can also unleash a lot of resistance from local inhabitants.

PREVENT WATER FLOWING FROM SEA INTO THE RIVER

A third possible hazard is the flooding from the sea. This has no direct effect on the city of Hue, because of the lagoon, but can greatly affect the situation of the river.

BARRIER

With a barrier between the river and the sea, uncontrolled water flow from sea into the river can be prevented. By means of this measure, the water level at the downstream part of the river will be lower in comparison with the sea level. For short storms the land can be protected from flooding. For storms of a longer duration this option is not suitable, because river water cannot find a way towards the sea resulting in a flood in the low lying areas.

2.3.4 POSSIBLE IMPROVEMENTS FOR THE WATER DEFENCE SYSTEM IN THE THUA THIEN-HUE PROVINCE

The next step is to formulate different possible improvements to the Thua Thien-Hue coastal system. The information from the analysis above will serve as a guideline in combination with the knowledge about the area. In the coming paragraph seven possibilities will be highlighted from which in the next paragraphs a few promising combinations will be set up, with the use of a multi criteria analysis.

1 – EASTERN BYPASS

The first possible improvement to the water defence system of the Thua Thien-Hue province consists of a bypass upstream of the city Hue. This bypass will act as a backup for the Huong River, redirecting the water away from the city into an artificial canal to the east. Here it will connect to an already existing river, which connects the Huong River with the large lagoon lake in the east. This small river will need to be upgraded in order to be able to cope with the huge increase in discharge during a yearly flood.
When a flood exceeds this level, the new river will not be able to relieve the Huong River up until the level that flooding will not occur. In this case, the area at the Northern side of the upgraded river will be sacrificed. The return period map shows that the whole area is a once in 5 year flood area. A section of this area must be downgraded towards an area that has a return period of once in two year flood area. The land use can be adapted into this new return period. The inundation area will be closed off on the western side by a dike placed along a northbound side-branch of the river. The total lay-out of the system can be seen in Figure 38.

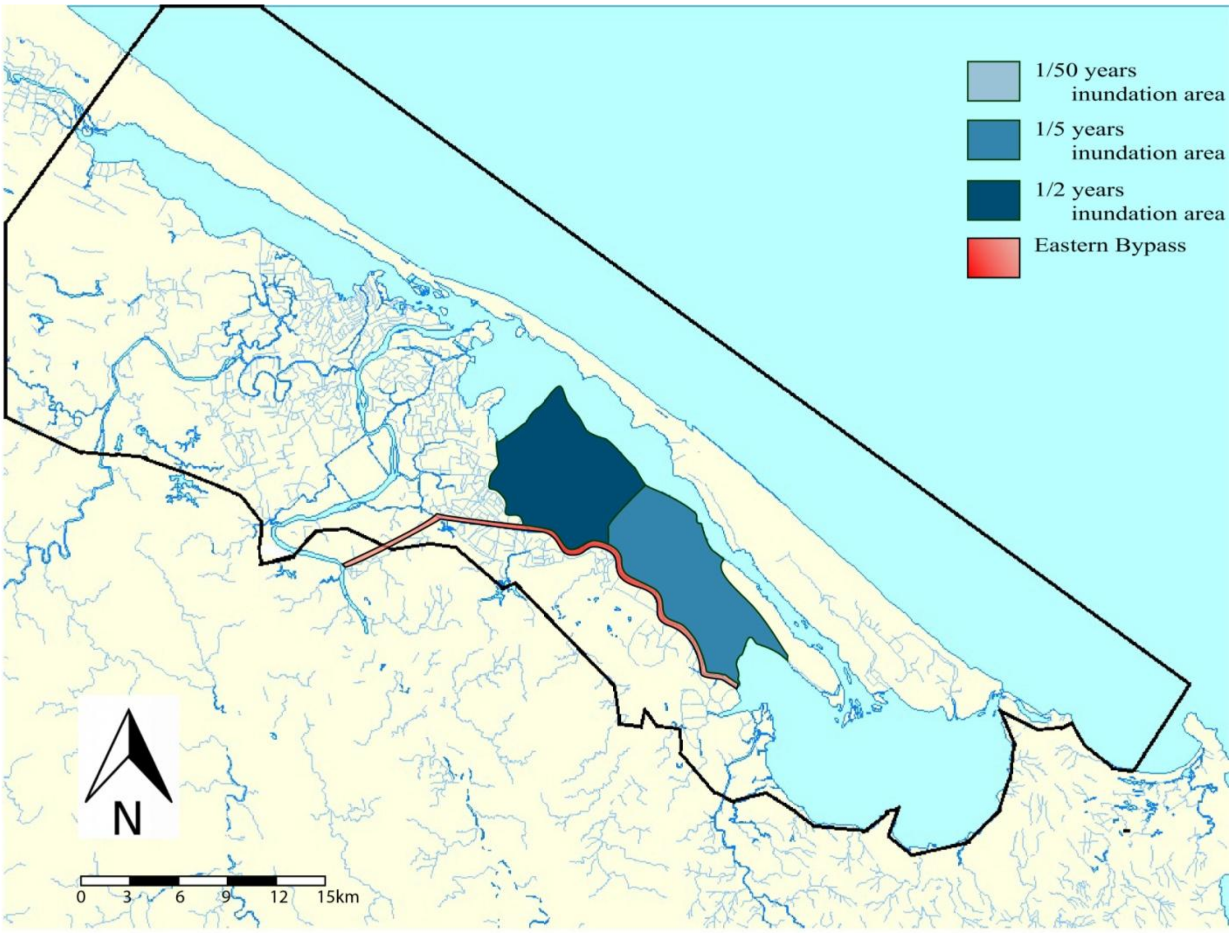


FIGURE 38: MAP OF THUA THIEN-HUE COASTAL AREA WITH EASTERN BYPASS SYSTEM WITH INTENDED POSSIBLE INUNDATION AREAS

ADVANTAGES

- Effective system of protecting the main city area
- Mostly uses already placed rivers
- Dikes are placed in low-density population areas
- Possibly flooded area is marked low value area

DISADVANTAGES

- High costs because of bypass system through a hilly area
- River has to be upgraded for a long stretch
- Possible overstressing of the lagoon
- Control structure needed to redirect water into the bypass

2 – WESTERN BYPASS

The second possibility also includes a bypass, but on the western side of Hue. On a spot upstream of the city of Hue the Huong River makes a sharp turn towards the northeast. On this spot, the water can be partly redirected towards the northwest towards another smaller river. The flow of the bypass follows the path of several smaller rivers, which will need to be upgraded. The water will be redirected into the stream of another river, which will need higher dikes alongside it to cope with the yearly floods. The inundation zone east of the river is a once in a 2 year inundation zone. The return period map shows that this area is a once in 5 year flood zone. So this area must also be downgraded.

When the water level exceeds the level of the yearly flood, extra measures are needed and the north side of the newly upgraded river can be inundated. This area is noted as a one in five year return period area. The area will be closed off on the western side by an upland area and will connect with the lagoon on the northern side. This can be seen in Figure 39.

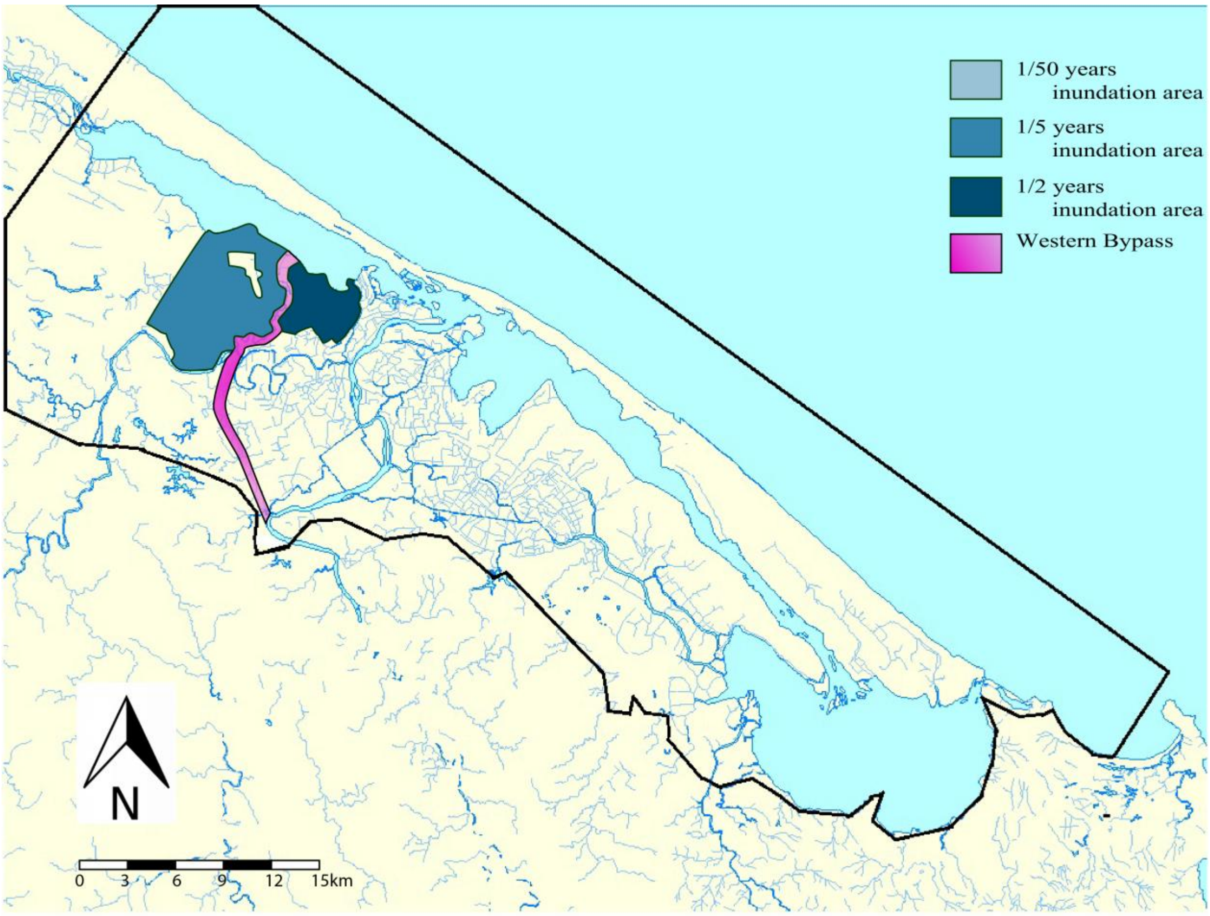


FIGURE 39: MAP OF THUA THIEN-HUE COASTAL AREA WITH WESTERN BYPASS SYSTEM WITH INTENDED POSSIBLE INUNDATION AREAS

ADVANTAGES

- Effective system of protecting main city area
- Mostly uses already placed rivers
- Dikes are mostly placed in low-density population areas
- Possible flooded area is marked as relatively low value area
- No mountainous or hilly area needs to be crossed

DISADVANTAGES

- Relatively small area can be used for inundation compared with the Eastern bypass
- Large control structure needed at bifurcation
- River and dikes have to be upgraded
- Possible overstressing of the lagoon
- Average value areas near flow of bypass (industrial) and inundation area (domestic)

3 – CITY CENTRE BYPASS

The third possible bypass is also on the eastern side of Hue. This one however tries to avoid the hilly area, by upgrading the side branch from the Huong River to the Lagoon Lake along the whole stretch. This does mean that the bypass will have to start very close to the high-value urban area. Dikes along the route to the Lagoon Lake will have to cope with the yearly floods. The location can be seen in Figure 40.
In case of higher floods, the same possibilities will count as the first eastern bypass. A large area on the eastern side of the Huong River can be inundated, protecting the city centre and its inhabitants.

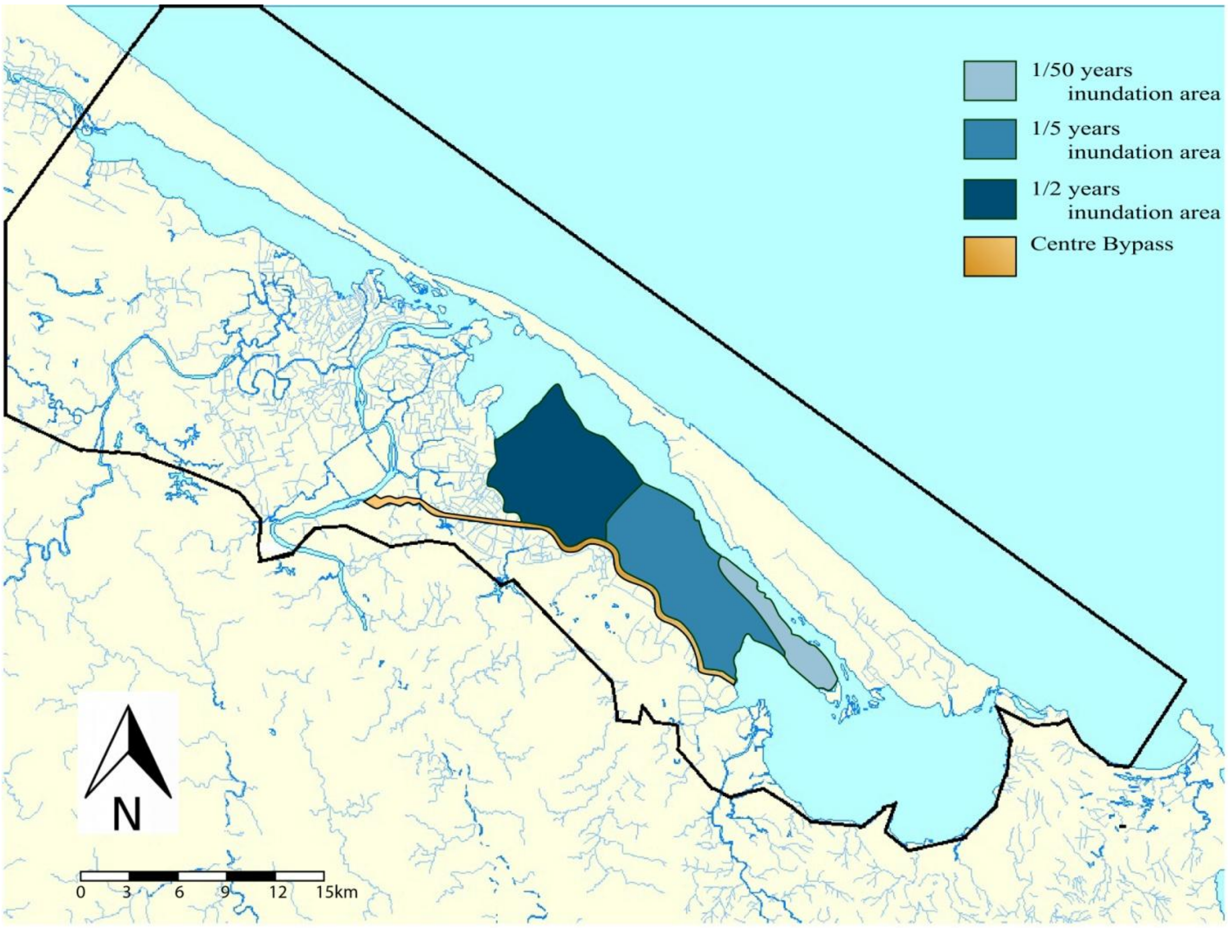


FIGURE 40: MAP OF THUA THIEN-HUE COASTAL AREA WITH CITY CENTRE BYPASS SYSTEM WITH INTENDED POSSIBLE INUNDATION AREAS

ADVANTAGES

- Will redirect water from the most flood-prone high-value part of Hue
- Only river upgrade needed
- Possibly flooded area is marked as low value area
- No mountainous or hilly area has to be crossed

DISADVANTAGES

- Bypass is constructed close to high-value area, possible problems when upgrading dikes
- Bypass location is downstream of early flooded area

- Hydraulic structure needed to redirect water into the bypass
- Possible overstressing of lagoon

4 – EXTRA INLET

This option is mainly focused on the interaction between the lagoon and the sea. When the flooding comes from the rivers, the lagoon will be acting as a basin where the water inflow from the mountains will be higher than the inlets can transport outwards to the sea. In past decades, the water inflow of the lagoon was slowed down by the flooding of the lands around the city of Hue, giving the inlets more time to prevent flooding of the lands around the lagoon. However, with a good water management plan in place, the water will be transported to the lagoon faster. This could lead to flooding of the densely populated lands around the lagoon. An extra inlet can be placed to increase the possible discharge from the lagoon to the sea. This inlet should not be used until floods occur to make sure that it will only have a minor effect on the current lagoon and to prevent the increase of risk for flooding from the sea.

The best place for the extra inlet would be in between the two other inlets. The chosen spot, which can be seen in Figure 41, crosses only a small distance of land in a low-populated area.

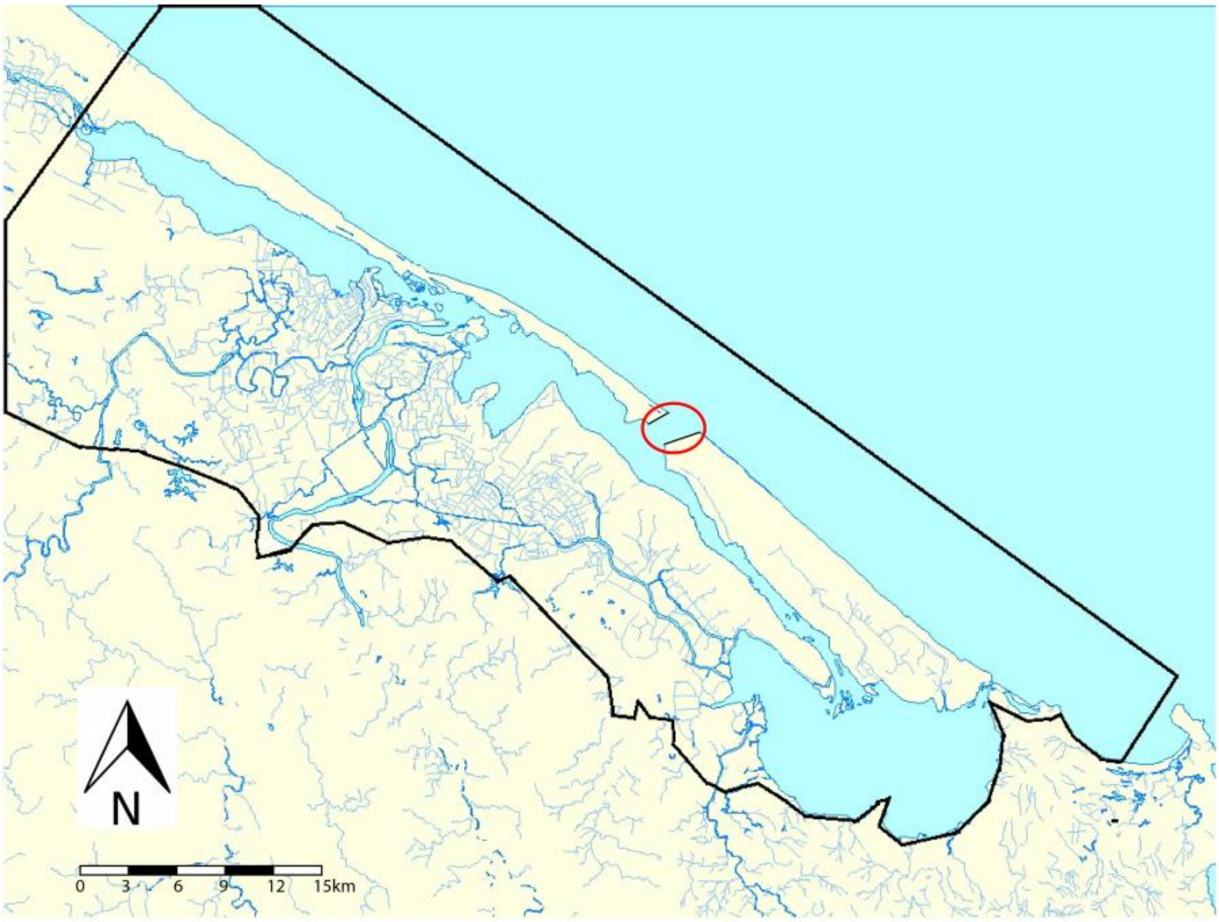


FIGURE 41: MAP OF THUA THIEN-HUE COASTAL AREA WITH NEW INLET SYSTEM (RED CIRCLE)

ADVANTAGES

- Increases outflow of water from lagoon to sea
- Can prevent damage to aquacultural fields and areas near the lagoon by minimizing water level rise

- Located in low-populated area

DISADVANTAGES

- Control structure needed to regulate flow
- Effectiveness needs additional research
- Has no great impact on floods along the Huong River

5 – CLOSURE DAM TO CREATE A RETENTION AREA UPSTREAM OF HUE

The fifth possible element differs from the others in a fundamental way. It does not try to redirect the flow into another path, but stores the water upstream of the city of Hue. During a storm the dam can be closed, which created a retention area at the upstream side of the dam in order to limit the flow through the Huong River as much as possible. This strategy is in line with the current strategies, where two large reservoirs are already in place to limit the flow of the Huong River. However, more capacity is needed during a storm and this option can provide.

The optimal location for the closure dam has been chosen to be near the confluence of the two rivers that together form the Huong River, as can be seen in Figure 42. This location is upstream of the city of Hue, at the edge of a mountain ridge, which will provide for the largest piece of the needed closure. The area near the confluence is a low-population area and a relatively small structure is needed to provide for large capacity. The dam will not generate electrical power and will only be closed when there is a chance of flooding downstream.

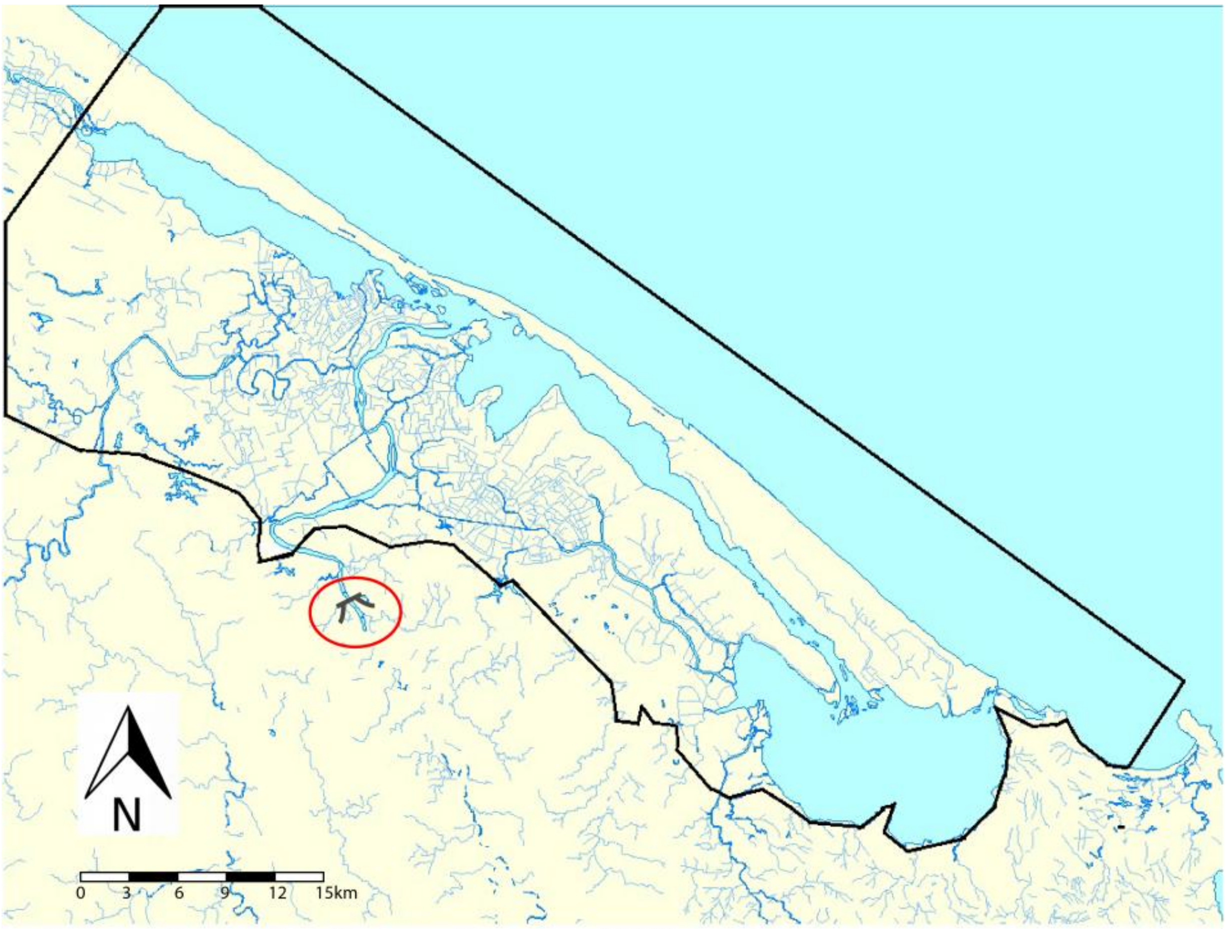


FIGURE 42: MAP OF THUA THIEN-HUE COASTAL AREA WITH LOCATION OF CLOSURE DAM (RED CIRCLE)

ADVANTAGES

- Limits the flow of water through the Huong River during a storm
- Relatively small closure dam is needed for large capacity
- Fits in the current policy
- When effectively used and made with sufficient capacity, it can prevent flooding of the entire area, without the need of flooding agricultural lands
- Saves water for drought season

DISADVANTAGES

- Can only limit water flow for limited amount of time
- Effective reservoir management needed to prevent long reaction times
- Can change the effectiveness of the current reservoirs
- Will inundate large area
- Expensive and high-maintenance closure dam needed

6 – EASTERN-HUE CANAL

This solution can be seen as an alternative to the eastern bypass. It involves the construction of a large capacity canal on the eastern side of Hue, which will be permanently inundated. The canal will act as a shortcut between the river upstream of Hue and the lagoon. In its path no current rivers are used in order to limit the canal length. It does cross an average scale river that flows from the centre of Hue in the west to the Lagoon Lake in the east. A control structure is needed here to make sure that most of the water will use the new canal without inundating the nearby lands.

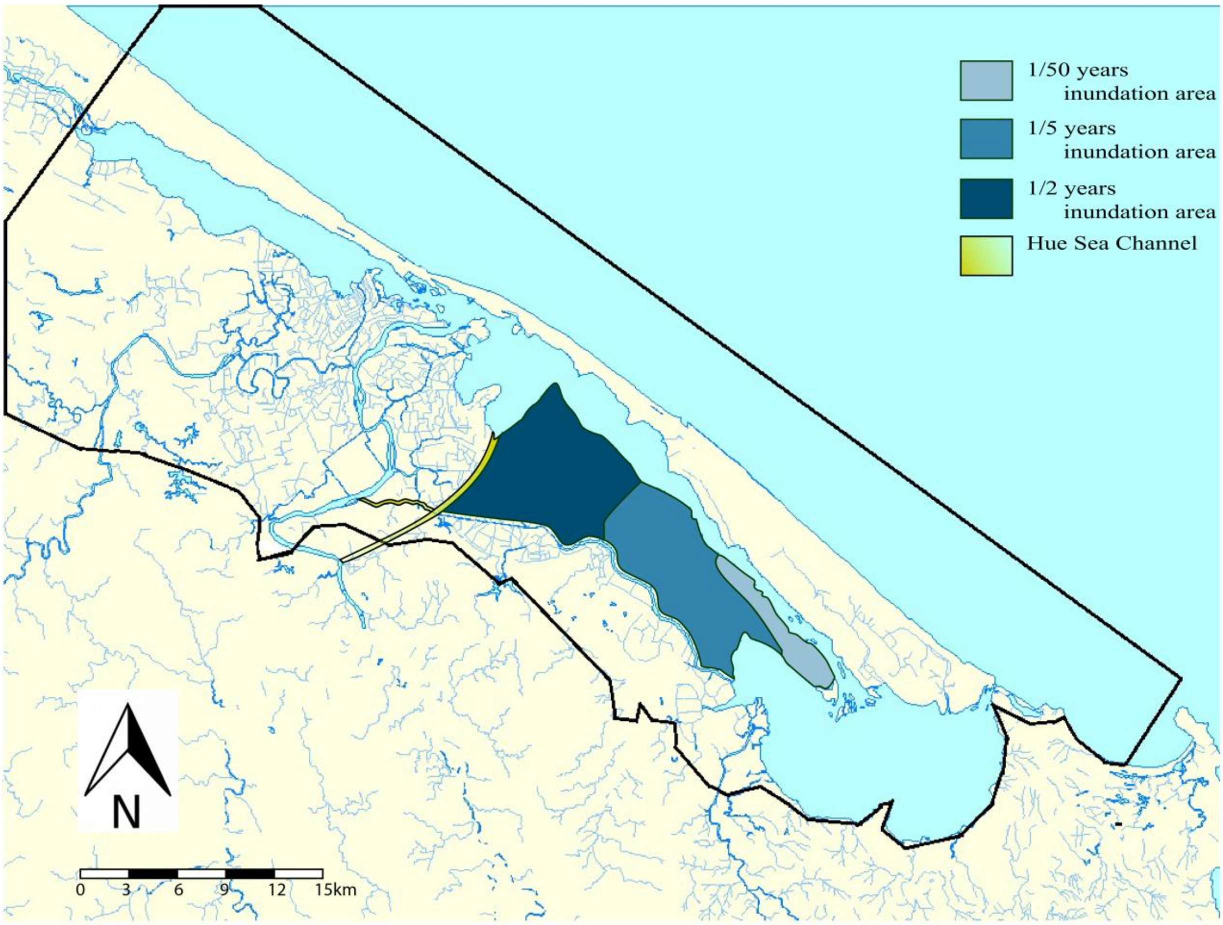


FIGURE 43: MAP OF THUA THIEN-HUE COASTAL AREA WITH EASTERN-HUE CANAL AND INTENDED POSSIBLE INUNDATION AREAS

This way the second part of the canal will be fed by two streams, from which the second is the river coming from the city centre. This river would need improvement over a small length. The river part to the east of the crossing will not need any improvements, as the control structure will regulate a steady and sufficiently low discharge. When seemed necessary, it can be possible to inundate the area to the northeast of the control structure in order to preserve the centre of Hue. This is graphically explained in Figure 43.

ADVANTAGES

- Effectively redirects the water around the city centre
- Permanent canal can function as shortcut for ships and increases the accessibility of the mountainous areas
- Canal and control structure build in low-populated areas
- Existing rivers will only need improvements over a small length
- Division of land with low-value areas in east, which can be inundate during high floods
- Control structure can redirect most of the water to the east for irrigation in times of drought

DISADVANTAGES

- Permanent canal needs flowing water, which can be a problem during dry season
- No existing rivers or canals are used, which results in higher costs
- Large control structure needed at the river-canal crossing
- High costs because of the path of the canal through mountainous areas
- Possible overstressing of the lagoon
- Control structure needed at the upstream end of the canal in order to redirect the flow

7 – PERFUME CANAL

The last considered possibility is to strengthen the Huong River in order to keep the river from flooding. In the current situation, the river floods at multiple places. This happens because of the combination of the enormous flow of water and the inability of the river to be able to handle this. The uncontrolled and unstandardized banks in combination with many obstacles in the river, mainly in the form of little islands and vegetation, slow down the flow and enhance the possibility of flooding in the highly-populated area. Improving the flow of the Huong River by improving the banks, clearing the flow of obstacles or standardizing the width of the river along the route to the lagoon, could improve the possible discharge of the river in such a way that flooding will occur less.

This would need a better and higher coordinated river maintenance system. In the current situation, the communes along the river can decide for themselves what kind of system they apply in their commune as long as it does not interfere with the main focus of the district- and provincial plans. Improving the river banks would mean that an integrated river board should be appointed which coordinates and maintains the improvements and defences along the river. An impression can be seen Figure 44.

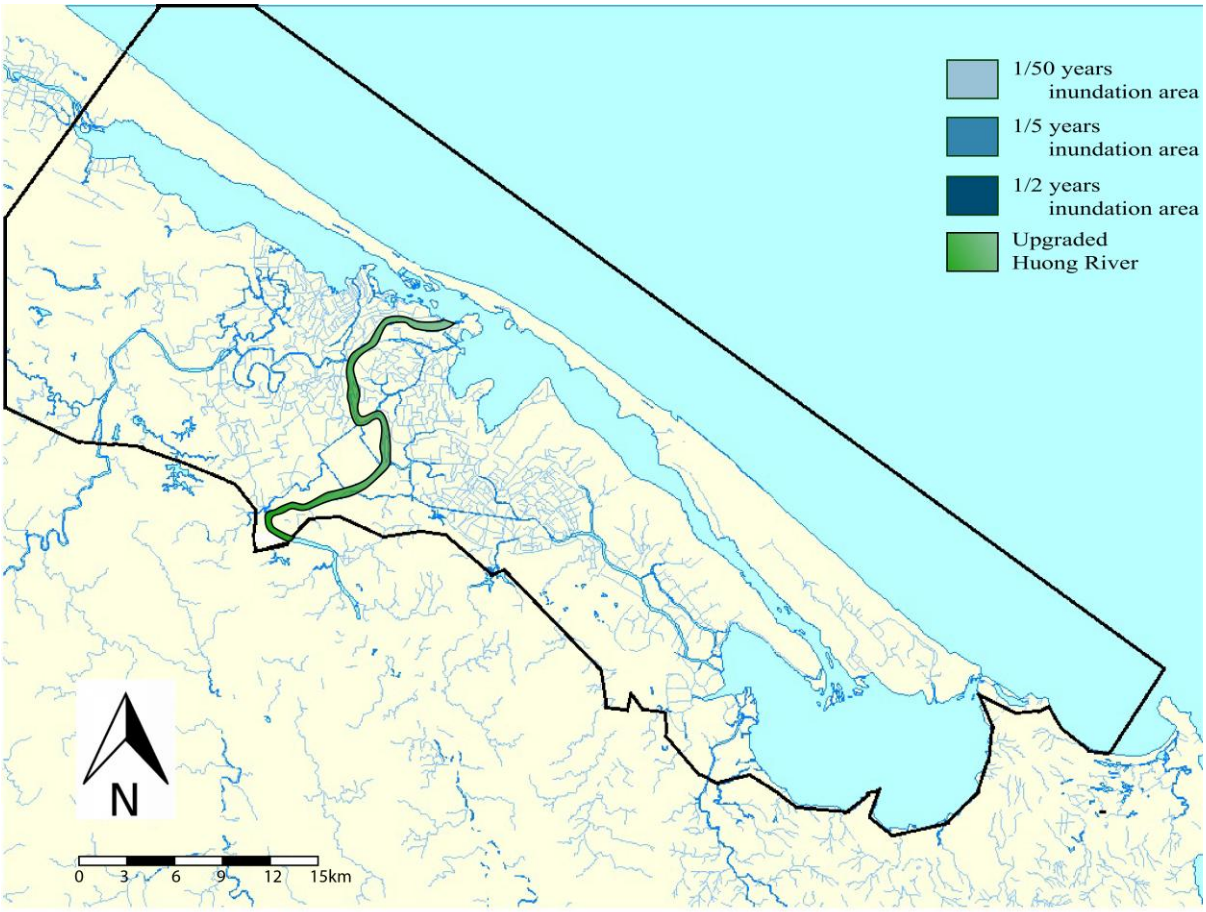


FIGURE 44: MAP OF THUA THIEN-HUE COASTAL AREA WITH POSITION OF IMPROVED HUONG RIVER SYSTEM

ADVANTAGES

- Improves the capacity of the main Huong River
- No newly built waterways needed
- Improves effectiveness of the upstream reservoirs
- If found effective, provides a solution without needing inundation of low-value areas

DISADVANTAGES

- Effectiveness needs more research
- Large policy changes needed for maintenance
- Constructions needed in high-populated area
- Possible overstressing of lagoon
- Largest obstacle is inhabited, will need special attention

2.4 MULTI-CRITIRIA-ANALYSIS

A multi criteria analysis is used to converge towards the most promising improvements, which will be elaborated further in the next stage of the design. Up until this stage, there are still many uncertainties about the implementation and the exact consequences of the different solutions. This is why the multi criteria analysis is not converged into only one solution, but multiple promising combinations are chosen to be further investigated. This way, one prevents that only a single solution is worked out in detail with the possibility that this solution does not appear to be feasible afterwards.

The criteria which are used are based on the wishes and requirements from the different stakeholders, together with the different functions of the water which are depicted in the systems analysis.

A differentiation is made in the importance of each of the criteria by means of a weighing factor. The scheme shown below visualizes how to arrive at the most promising solutions:

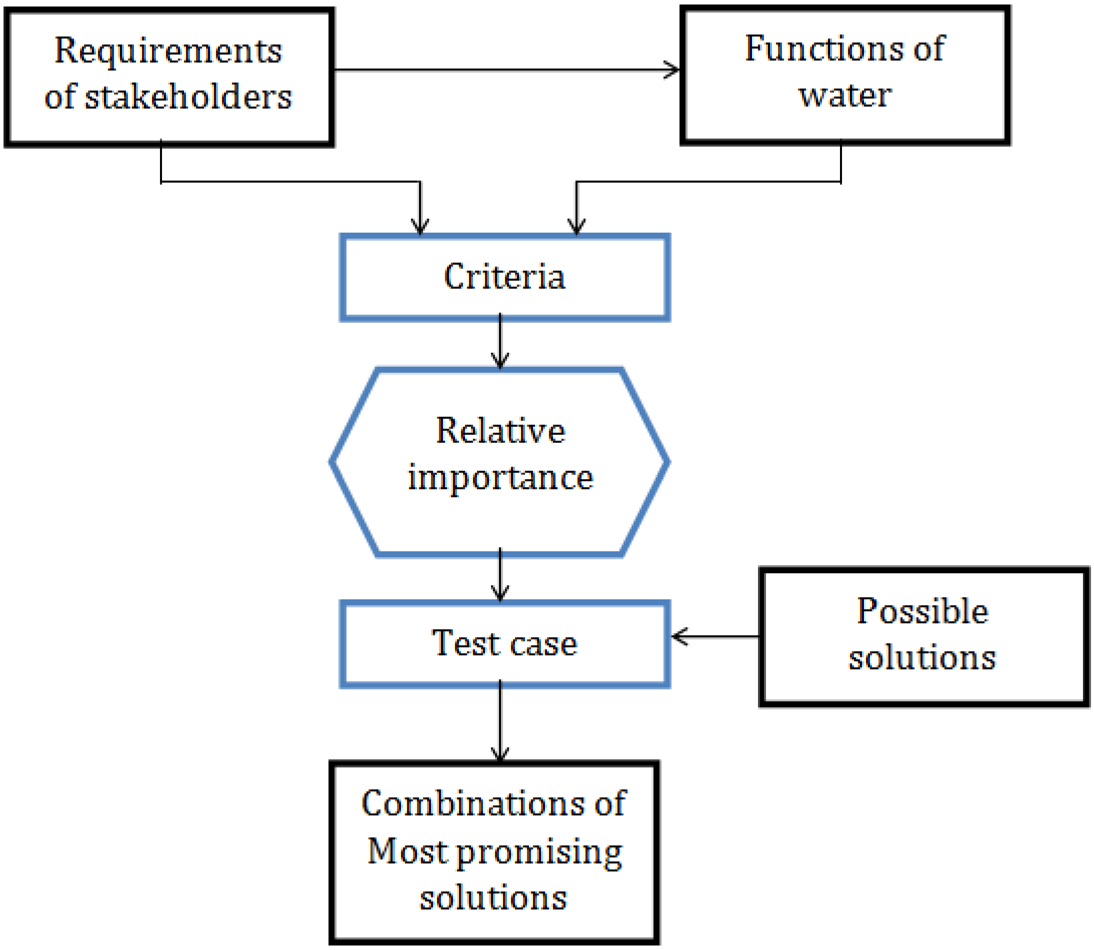


FIGURE 45: SCHEME FOR VISUALISATION THE ROAD TO ARRIVE AT THE MOST PROMISING SOLUTIONS

2.4.1 USED CRITERIA

Flood damage reduction: What will be the effect of a certain measure on the damage of the floods in a financial sense?

Human safety: What will be the effect on the predictability of the flood? What will happen to the available time for the people to be evacuated?

Availability of fresh water throughout the year: What is the effect of the measure on the available of fresh water, especially during the dry period? Will there be any significant change in the water quality?

Limitation of salt water intrusion: What is the effect on the salt water intrusion from sea into the river?
Nature conservancy: Will the proposed measure do any damage to natural areas, or will there perhaps even be an increase in natural value?

Navigability of the river: What is the effect of the proposed measures on the depth, width and flow velocities of the river? Do the channels still fulfil the requirements from a navigational point of view during the year?

Durability: For how long will the proposed measures last? Will there be any degradation in time?

Aesthetic view: What is the overall look of the structures? Do they have any potential to be landmarks in the future? Will the measures have any negative impact on the landscape?

Maintenance: Is there a lot of maintenance needed in order to keep the system in the state for which it was designed? One can think about dredging works or dike maintenance

Constructability: How much effort will it take to construct the proposed structures? Is there enough equipment, manpower and material available?

Costs involved: What costs are approximately involved with a certain measure and how are they related to one another?

Social acceptance: Will the plan be approved by the government and the community or will there be a lot of resistance, for example because a lot of people will need to leave their houses?

The relative weight is given a value in the range 1-5 while the performance of a measure is given a value in the range 1-10 per criterion. The total performance of a certain measure is the summation over all the criteria of the relative weight times the performance on each criterion. If a measure does not affect a criterion at all, it is given a value of 5.

TABLE 6: THE RESULTS FROM THE MULTI CRITERIA ANALYSIS

	Relative weight	Extra inlet	Retention Area	Eastern Hue canal	Perfume canal	Eastern bypass	Western bypass	City centre bypass
Criterions								
Flood damage reduction	5	4	9	6	6	7	7	6
Human safety	4	5	6	6	6	7	7	4
Fresh water supply	4	5	7	5	5	5	5	5
Limitation of salt intrusion	3	4	6	5	5	5	5	5
Nature conservancy	4	4	4	4	3	4	4	4
Navigability	2	7	7	5	5	5	5	5
Durability	3	5	7	7	7	7	7	7
Aesthetic view	3	8	7	4	4	6	6	5
Maintenance	3	8	7	5	5	6	6	6
Constructabil ity	3	7	6	4	4	5	5	4
Costs	4	8	5	5	4	6	6	4
Social acceptance	4	7	5	5	6	6	6	3
Total score		**246**	**266**	**215**	**211**	**244**	**244**	**201**

From the MCA can be seen that the city centre bypass provides the least promising improvement. This is mainly due to the location of the canal that needs to be upgraded to become a bypass. This canal is near the city centre and flows through a very densely populated area. A lot of people must be relocated, when the canal must be upgraded. Furthermore, the bypass leads a massive amount of water closely around the city centre during a flood. So, when something goes wrong, it hits the city centre immediately.

The options can be divided into three categories: water retention, flood routing and creation of an inlet.

Based on the MCA the water retention seems plausible to be beneficial. Although some natural areas will be lost because of the inundation of a large area during high discharge, the reduction in damage caused by the flood seems to be of greater importance.

The creation of an extra inlet could be beneficial as well, although it is not very clear what the effects would be in terms of risk reduction. This is an interesting point to investigate further on.

For flood routing it appears that both the Eastern bypass and the Western bypass seem to the best solutions to divert the discharge from the Huong River when the capacity is exceeded. By applying these options, the least damage of all options is done by the excess of water flowing through the new channels.

2.5 PROMISING COMBINATIONS FOR THE WATER DEFENCE SYSTEM IN THE THUA THIEN-HUE PROVINCE

From the seven possibilities, 2 promising combinations are made from the results of the multi criteria analysis. Those combinations will be worked out in the in depth analysis. The promising combinations followed from evaluating upon the advantages and disadvantages.

2.5.1 COMBINATION 1: EAST AND WEST

The first combination combines both the eastern and the western bypass in one highly adaptable and redirecting system. On full capacity, the bypasses will lead huge amounts of discharge around the city of Hue. In the high-value and high-populated area no adjustments are needed as all of the dikes and both of the bypasses operate only in low-value areas. The aim is to limit the amount of water running through the Huong River at the location of the inner city, which will make it easier for this area to cope with the water, as rain is their only problem left. To make sure that lagoon will not overflow the nearby high-value lands, an extra inlet can be placed according the previous explained plans. This combination optimizes the idea of the Framework, where different areas are given different return periods and inundation of areas can be controlled during the flood. Areas flood because they were appointed to flood due to their low value, which highlights the extensive ability to control the situation. An impression of the combination of measures can be seen in Figure 46.

FLOODING SITUATION

At the normal situation, no bypass will be in use and the Huong River will act as the only waterway, similar to the current situation. In storm season, at the yearly flood, the first bypass will be put to use. The best way to do this is to use the Eastern bypass, as this one is situated further from the city and the bypass connects to an already high-capacity river. No lands will be flooded, as this eastern-going river will spill this water into the Lagoon Lake in the southeast. When the water level rises further, the second bypass will become operational. This will send the needed discharge to the northwest, where it will meet another river going to the lagoon.

Again no lands will be flooded as the capacity of the rivers and bypasses should be enough to keep the Huong River at a sufficiently low water level.

When the water exceeds the one in two year water level, the capacity of the improved rivers won't be enough to cope with the enormous discharge. At this moment the first fields will be used as storage area. The bypasses will still redirect the water, but instead it will be used to flood the appointed areas at the east and northwest of the city of Hue. With the use of these inundation areas, the highest discharges will be dampened and the high-value centre of Hue will still experience no problems from the river.

If the water level continues to rise up to and beyond the one in five year water level, additional areas will be appointed to inundate in order to keep the river discharge of the Huong River the same at the location of the city centre. This happens again at the one in 50 year discharge.

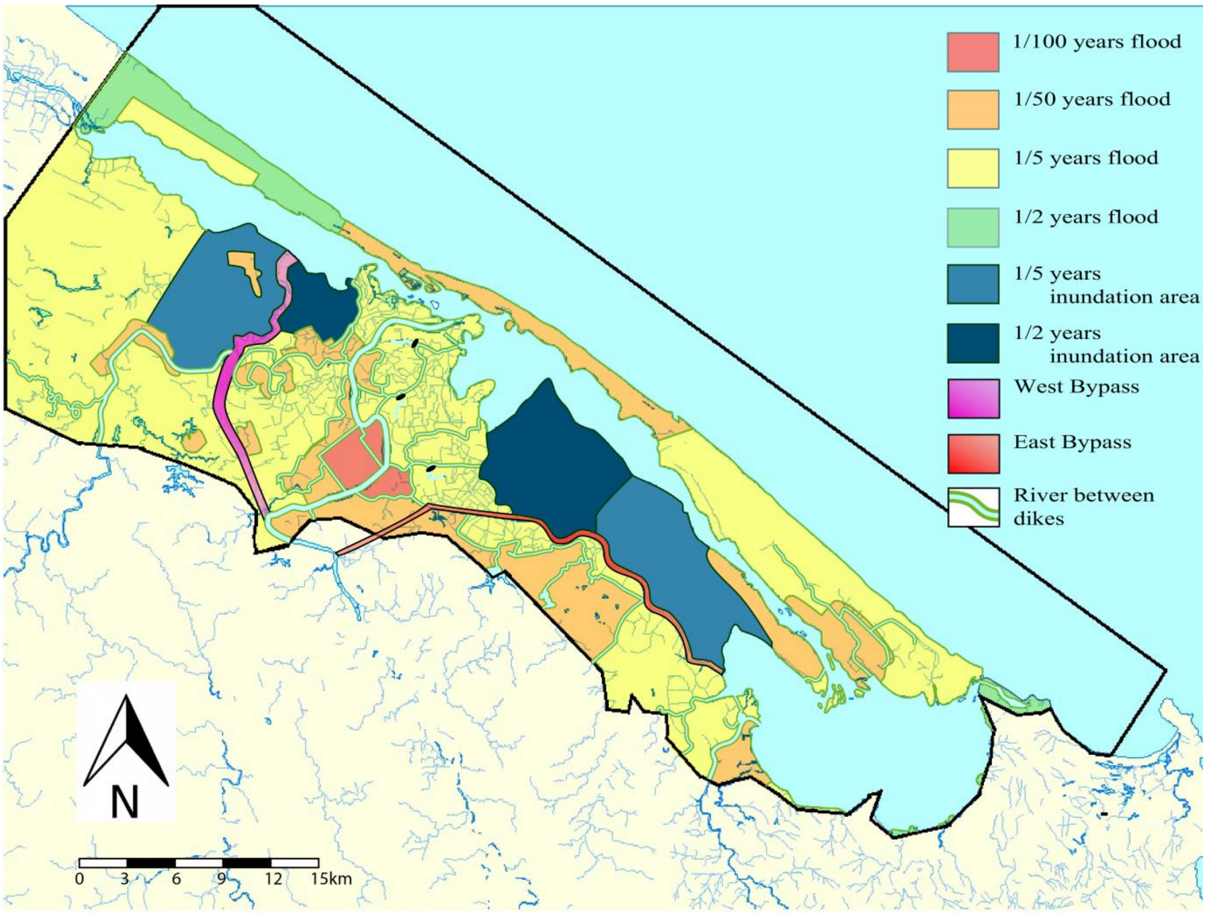


FIGURE 46: MAP OF THUA THIEN-HUE COASTAL SYSTEM WITH THE TOTAL LAY-OUT OF COMBINATION 1: EAST AND WEST, WITH CORRESPONDING INUNDATION AREAS

COMBINATION 1: EAST AND WEST INSIDE THE FRAMEWORK

The very adaptable and diversified water defence system fits perfectly within the Framework of Integrated Water Management. The water defences are organized in a way that every area is protected in the economically most optimal manner, without neglecting the other functions of the water in the area.

All connections with the sea are kept open and in a normal situation no new connection with the sea will be in place, which means that there will be no changes to the salt intrusion and the aquacultural farmers that rely on the brackish water will not experience new problems because of changes in the salinity or the availability of brackish water.

Because there are no changes to the normal situation, shipping will find no additional problems as well. During construction the route from Hue to the mountainous areas upstream can be some source of difficulties, due to the construction of two control structures, but the finished structures should have the availability of transportation over water as one of the main requirements.

In this combination, no additional storage capacity is placed inside the Thua Thien-Hue's coastal area. However, with two large reservoirs upstream of the Huong River and one large reservoir under construction mainly built for irrigation purposes, this problem will not occur on the large scale as it has done the past decades.

When the water defences are in place, maintained and working as planned, the area will experience a boost in wealth. The situation sketched by the implementation of this combination of measures will make sure that everybody in the coastal area knows what they are up against and what they can expect. Housing prices and choice of crops can be altered to perfectly fit the chance of inundation set by the province. As the route of the floodwater is known, precautionary measures can be taken before the rainy season to ensure that no loose rubble can be washed away by the rising water in order to damage buildings and lands in the area. Repair works can be planned and completed quicker and more efficient and human casualties can be held to minimum.

REQUIRED CONSTRUCTIONS

In order to construct the measures from Combination 1: East and West, the following constructions are needed:

- Eastern Bypass, consisting of:
    - Control structure in the Huong River
    - Straight gully through mountainous area
    - Dikes alongside the gully

- Western Bypass, consisting of:
    - Control structure in the Huong River
    - Upgrading of existing waterways to the northwest
    - Dikes alongside the upgraded waterways

- Upgrading of the eastern area, consisting of:
    - Upgrading of the An Cu'u River, flowing from Huong River to the Lagoon Lake
    - Placement of dikes along the An Cu'u River and the northbound side branch along the TL3 and the shortcut to the lagoon
    - Placement of dikes along the high return period area in the east
    - Control structures to enable controlled flooding

- Upgrading of the western area, consisting of:
    - Upgrading of the Bo River, between the connection of the bypass and the lagoon
    - Placement of dikes along the Bo River and surrounding areas as appointed in the figures
    - Placement of dikes around the high return period area in the west
    - Control structures to enable controlled flooding

- (if necessary) Construction of third inlet system and corresponding control structure

2.5.2 COMBINATION 2: LAKE HUE

The second combination combines the advantages of two possible solutions. The first line of defence is placed in the form of a retention area, storing the water to dampen the peaks of rainfall in the urban area. This area will be placed near the confluence upstream of the city of Hue. The second line of defence is placed in the form of a spillway at the eastern side of the retention area. This spillway will redirect the water away from the Huong River in the same way as the eastern bypass would do, with the difference being that this spillway is placed higher and more upstream. The spillway will connect the retention area with the An Cu'u River to the northeast. This river will need further improvement to be able to cope with the extra discharge coming from the spillway.

By planning not only the construction of the retention area, but also the construction of the spillway, the water is being stored as well as redirected. All the proceedings will be done in low-value and low-populated areas and at full capacity of the spillway, partly inundation of the lands to the east can be made possible to protect the high-value city centre even more. A third inlet in the lagoon can prevent flooding of the areas close to the lagoon. An impression of the combination of measures can be seen in Figure 47 .

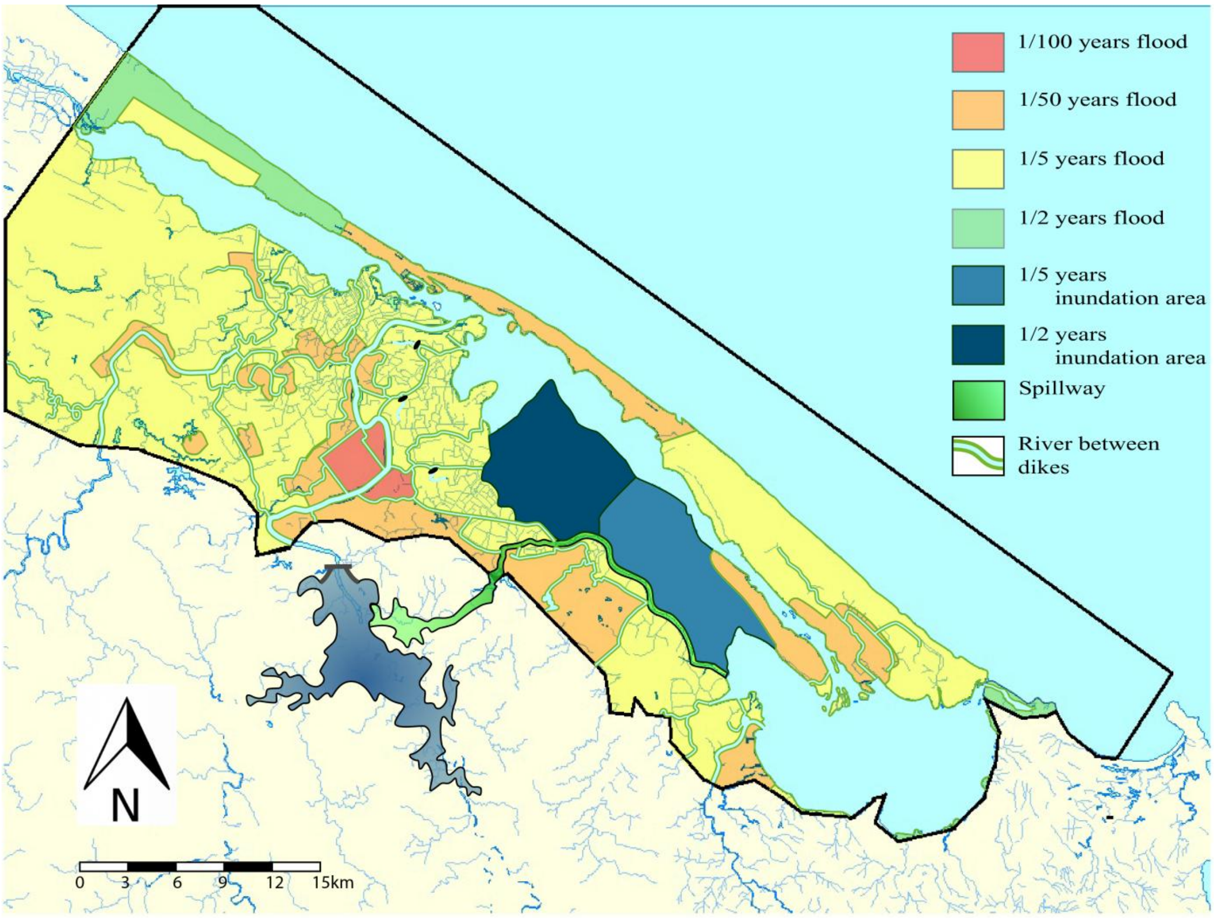


FIGURE 47: MAP OF THUA THIEN-HUE COASTAL SYSTEM WITH THE TOTAL LAY-OUT OF COMBINATION 2: LAKE HUE, WITH CORRESPONDING INUNDATION AREAS

FLOODING SITUATION

Before the start of rainy season and dry season, the retention area is a place where low valued agriculture can be practised. This retention area should be the last to fill up when the storm hits the area. At the yearly flood, the area should be able to store the wanted amount of water. If the water rises further, the spillway will be put to use and the water will be redirected towards the Lagoon Lake. In this scenario, no lands will have to be flooded, only the land which is used as retention area.

If the flood level rises past the one-in-two year storm, the upgraded An Cu'u River will reach its capacity limit and agricultural lands to the northeast of the spillway-An Cu'u River confluence will be flooded in order to prevent uncontrolled flooding.

As the water rises past the one-in-five and the one-in-fifty year storm mark, more areas will flood to prevent that the inner city of Hue will have to cope with a flooding situation. Only when the one-in-hundred year water level is passed, the spillway will be at full capacity and the new retention area will have to spill additional water into the Huong River, possibly flooding the high-value areas.

COMBINATION 2: LAKE HUE INSIDE THE FRAMEWORK

The combination of the storage and redirection of the water upstream of Hue will result in an additional amount of water that can be stored during a storm and being released when the storm is over.

To the east of the city of Hue, agricultural lands are appointed to flood first, at a rate of one-in-two and one-in-five year. Giving these lands a higher amount of safety will economically be a waste of money in comparison to the possible damage and occasionally some floods are needed to fertilize the lands with fresh sediment. Giving these lands a higher safety would need higher and more expensive dikes around the An Cu'u River, which would mean even more forced removals of inhabitants.

The transport along the Huong River will only experience minor changes, as the route into the mountains is blocked a few kilometres more downstream in comparison with the old situation. However, from the lagoon to the new dam no new construction or changes are needed to the Huong River, which means that in the economically most important region no changes will be felt.

The reservoir can also be used as a permanent reservoir in the future, if the climate change causes that the area has to deal with more droughts. Then there will be an additional reservoir that can store water that can be used during the dry months. This can make a significant difference when it comes to the wealth of the farmers. Not only can they harvest more because of the lower risk of flooding, but also do they have more water for irrigation available.
If necessary, an extra inlet can be constructed to increase the outflow of water from the lagoon to the sea. The chance that this will be found necessary will be smaller in comparison to the other combinations, because of the smaller amount of water reaching the lagoon.

REQUIRED CONSTRUCTIONS

In order to construct the measures according to Combination 2: Lake Hue, the following constructions are needed:

- Lake Hue retention area, consisting of:
    - Building the necessary dams to keep the water in place
    - Constructing new infrastructure to keep the dams and mountain towns accessible also when the retention area is filled.

- Lake Hue Spillway, consisting of:
    - Straight gully through mountainous area from Lake Hue to An Cu'u River

- Dikes along the gully
- Control structure to regulate the flow through the spillway

- Upgrading the eastern area, consisting of:
  - Upgrading the An Cu'u River between the spillway and the Lagoon Lake
  - Placement of dikes along the An Cu'u River and the northbound side branch along the TL3 and the shortcut to the lagoon
  - Placement of dikes along the high return period area in the east
  - Control structures to enable controlled flooding

- (if necessary) Construction of third inlet system and corresponding control structure

2.6 DISCUSSION

When a framework for integrated water management is made, a lot of assumptions and choices have to be made. These reflect the values as seen by the authors. Some choices are made to simplify the situation, and others are made to signify a value of something or someone.

In the analysis of the flood maps of Thua Thien-Hue, no real choices needed to be made. But limitations on the availability of data have led to some assumptions and simplifications. Flood maps show the extent of the flooding at a certain point in time. No clear description of flood progression can be made with the spatial resolution of satellite data. Water depth is also not discernable from radar images, making it a 1 dimensional image at a single point in time. Fieldwork, with observations and interviews, does shed some light on these blind spots. But these observations have a very low spatial resolution. The combination of these data result in some form of hazard map, although this map is hard to compare with hazard maps that result from vulnerability analysis on the one hand and results from model simulations on the other.

The land uses in the project area have led to a map indicating the desired return periods of flooding. The areas with agriculture, aquaculture and plantations are designated with a lower priority than areas with a higher population density or locations with special infrastructure, like the Phu ba airport and industrial terrain. This choice was made based on the value of the area. Agriculture in the area has adapted to flooding by planning the harvest before the wet season and refraining from growing crops during periods with a high risk of flooding. Distinction between agriculture and plantations were initially made, but observations in Hue did not show a significant difference in land use and this distinction was abandoned. The distinction with aquaculture is still in place, as flooding of already flooded areas leads to less, but still some damage. Also, the recovery abilities are considered to be better for aquaculture than for agriculture.

As for the return periods for populated areas, densely populated areas received a higher return period than sparsely populated areas. One reason for this choice is the value of property. But more importantly, the recovery capacity of the inhabitants of rural settlements was high. Houses are built in a way that the loss of value is relatively low compared to their counterparts in the city centre. Valuable belongings were often located on the second floor, and the interior could stand some water damage. Using this recovery capacity to keep the return period low compared to urban areas makes it easier to design a protection system that has a positive cost benefit ratio.

3. IN DEPTH ANALYSIS

In this chapter the promising combination are worked out to get to a preliminary design. First, more information is given of both combinations. Also some global dimensions are calculated in this part, which can be imported into the SOBEK model. The output of the model is used to see which of the two combinations turns out to be the most effective on the system boundary. This all is done in order to see the effectiveness of the two combinations. This is shown in the section 'Assessing the effectiveness". After this, the preliminary design is made for the combination which showed the best result in the SOBEK model. Section 3.3 will highlight the consequences of the combinations for the hydrological functions within the system boundaries. In the end of this chapter flood proof houses will be discussed and a discussion will be given.

3.1 ASSESING THE EFFECTIVENESS

In the end of chapter 2, two promising combinations were made. In this part these combinations will be assessed on their effectiveness. First, both combinations will be worked out in order to get some dimensions which can be imported into the SOBEK model. In the SOBEK model the combinations will be tested on their effectiveness. The output of the SOBEK model will be used to see which combination is the most promising to work out in further detail.

3.1.1 COMBINATION 1: EAST AND WEST

For the first designed scenario, two new canals have to be built, see Figure 46. One canal is starting at the Huong River and flows in the direction of the Tu Ha region in the northwest towards the Tam Giang-Cau Hai lagoon. The first 8 kilometer consists of a new canal that has to be built. This canal starts at the Huong River and crosses the major road TL1. After this point the canal merges with the existing Bo River and flows for the next 10 kilometers to the North-East before water enters the lagoon. The Bo River is not large enough to cope with the additional discharge from the bypass, which means that it has to be enlarged.

To reach the desired distribution of discharges over the river and bypass an adjustable weir in the Huong River has to be built to regulate the water flow in times of flooding. Due to this weir, water will flow into the canal to prevent the City of Hue from flooding. Because the canal must be able to handle large quantities of water, there must be enough space available to build this canal. A lot of houses are located around the first 1500 meters of the bypass canal. For the next reach towards the merging point with the Bo River the canal can be designed meandering through the area avoiding small villages and houses. The reach can be designed without meandering, but it will result in the destruction of a lot of houses.

Some decisions have to be taken into account whether it is worth it to demolish the houses for flood prevention in the future. Choosing this option, removing people's homes can call a lot of resistance from local inhabitants. It is up to the politics to make a consideration between this option of flood safety and the price people want to pay for that.

After the first part the bypass canal merges with the Bo River. The problem arises that near the confluence both banks are covered with houses. Here, the same decisions as before need to be made.

The second bypass canal starts further upstream of the Huong River and flows parallel to the street Tu Duc. After that, it follows the existing ditch/river called An Cu'u River to the Cau Hai lagoon. The first 6 kilometer of the planned bypass canal must be built through residential areas.

Also here policy makers have to discuss the benefits and disadvantages for this option. Destroying houses and other buildings will most likely cause a lot of resistance.

At the end of both bypass canals an area is designated for water storage. At the end of the eastern bypass system, the area is subdivided into two parts. One part is designed to store excess water once every two years and the other one is designed to store excess water ones every five years. At the end of the western bypass system the area is divided into 3 different inundation areas. Being an area for excess water occurring once every two years, once every five years and the extra and last one is suitable for once every fifty years. The entire area which stores excess water every two years must be downgraded, because the return period map assigned this area to be flooded once in two years.

The idea behind the system is that temporary areas are used as inundation area. The deficit of water can be stored in order to prevent the city of Hue from flooding. Because the City of Hue and its historical centre are located near one of the lowest points of the delta in the Thua Thien Hue Province a lot of water during the time of rainy- and typhoon season will flow into the city. When the area just mentioned is denoted as storage area, less damage will be inflicted to populated areas. In the same way there has to be looked at the discussion of moving people their houses in order to design the storage areas. Because water will be directed to those areas the chance of flooding will be increased significantly. Dikes have to be built surrounding the storage areas to prevent water flowing back overland to the lower-lying area near the city of Hue. Soil dug from the new canals can be used to construct those dikes.

Water can flow from the storage areas to the different lagoons. To prevent that the water level in the lagoon becomes too high, an extra inlet is designed between the Thuan An and the Tu Hien inlet. By construction of this new inlet water can easily flow towards the sea without using and overloading the existing inlets. Additional research is required to investigate if the inlet is morphological stable and to study the effect of sedimentation on the bypass systems.

When creating a new bypass canal also new infrastructure has to be created, for example a bridge. Along the Bo River infrastructure has to be adapted to the widened river. There are two bridges crossing the Bo River. Both need to be adapted.

The canal is designed next to some high mountains where rock and hard soil layers can be expected. Some further investigation is required in order to get more information about these layers and to get an answer to the question if excavators are able to dig soil out or if explosives are required to do this. This also applies to the other area where a canal has to be excavated.

ROUGH CALCULATIONS TO ASSESS ORDER OF MAGNITUDES

In this scenario two bypasses are designed. In order to regulate the contribution of the flow between the two bypasses and the Huong River itself, some control structures are necessary.

When the areas in the hinterland with a return period of once in a hundred years are protected, discharges of 6918m^3/s and 3310m^3/s from the Huu Trach and Ta Trach rivers create the maximum discharge of 10.228m^3/s in the Huong River. Because this magnitude of flow is only occurring in the one in hundred years flooding and only during a single hour of a storm event, in this chapter there will be calculated with a maximum discharge of 80% of a once in 100 year discharge, this results in a discharge of 8.000m^3/s. The maximum flow that the lower part of the Huong River can handle without flooding, according to the SOBEK model, is 600m^3/s.

Because both bypasses are flowing through an urban area and in both regions, the bypass will cause inconvenience for local inhabitants. It is decided that both bypasses will get the same dimensions. This means that both rivers must be dimensioned and prepared for a discharge during an extreme event of:

$$Q_{bypass} = \frac{8000 - 600}{2} = 3700\ m^3/s$$

This means that at the first bifurcation 3700m³/s will flow into the bypass and that 8000 – 3700 = 4300m³/s will flow through the Huong River until the second bifurcation where 3700m³/s will flow in the second bypass and the remaining 600m³/s will flow through the Huong river to the city of Hue.

During the dry season, the flow in the Huong River should be 25m³/s (Cat 2011). This discharge is mainly for environmental reasons to counteract the salt intrusion. This means the bypasses should not take part of the discharge. An overview of the discharges is given in Table 7. Furthermore, in Figure 48 a schematization of the distribution is given.

TABLE 7: REGULATION OF DICHARGE

	Discharge extreme event [m³/s]	Percentage	Discharge drought [m³/s]	Percentage
Upstream	8000	100 %	25	100 %
Bypass 1	3700	46.25 %	0	0 %
Bypass 2	3700	46.25 %	0	0 %
Huong	600	7.5 %	25	100 %

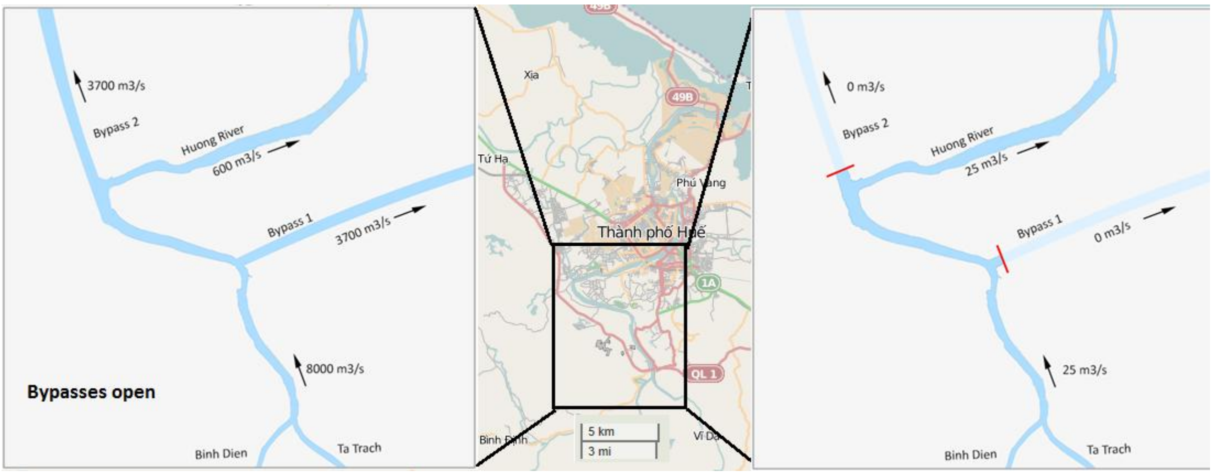


FIGURE 48: DISTRIBUTION OF DISCHARGE DURING HIGH AND LOW DISCHARGE

A hydraulic structure is needed to distribute the flow over the multiple waterways. Table 7 shows that there is a big difference in the function of the bifurcations. Where the regulating structure has to stop all water flow in times of drought, it has to pass 3700m³/s during an extreme event. This makes the designing of such a structure very challenging.

POSSIBLE STRUCTURES FOR DIVIDING THE DISCHARGE

To come up with a solution for a regulation structure at the bifurcations, an overview of the possibilities will be given. At the point of the bifurcations there is hardly any head difference available to work with. Because of this reason it is very challenging to make only one structure in one of the branches. Most constructions can pass or stop the water flow but they are not able to stop or just let flow the water in the other branch in the absence of any useable head difference. A solution has to be designed where there are constructions in both branches or there is one construction upstream of the bifurcation.

First the dimensions of the bypasses will be roughly calculated. The width of the bypass is calculated with the Chezy formula. The same Chezy constant as in the SOBEK model is used ($C = 43.6$ m^{½}/s). On a horizontal distance of 12.5 km the bottom level drops 1 meter, so the average slope $s = 1/12500$. Furthermore, a maximum waterdepth of 10 meters in the bypass is assumed which gives. $y = 10$

$$A = (b + y) * y$$

$$R = \frac{A}{b + 2 * y * \sqrt{2}}$$

$$Q = C * A * R^{0.5} * s^{0.5}$$

Filling in the above equations gives a width of the bypasses of $b = 300\ m$.

OPTION 1: ORIFICE

This option contains a wide movable orifice in both branches. In times of extreme floods the orifice in the Huong River can be lowered and closed in such a way that only a maximum discharge of 600m^3/s can flow through. The remaining 3700m^3/s water can flow via the western orifice through the second bypass channel.

In times of drought the orifice in the bypass river can be closed and the available flow of 25m^3/s can go through the Huong River to the lagoon.

Because the width of the river, 300 meter, is too large to use one single moveable orifice, multiple orifices next to each other will be used. A side view of the orifice can be seen in Figure 49 and a spatial representation can be found in Figure 50.

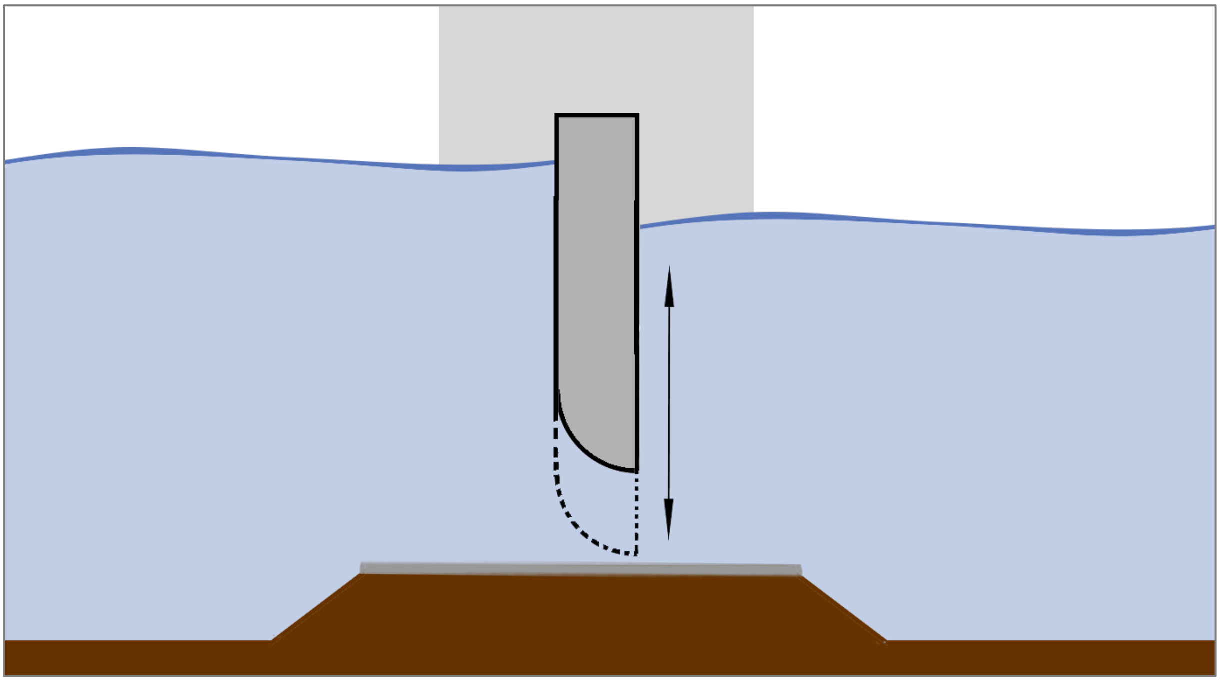


FIGURE 49: SIDE VIEW OF THE ORIFICE

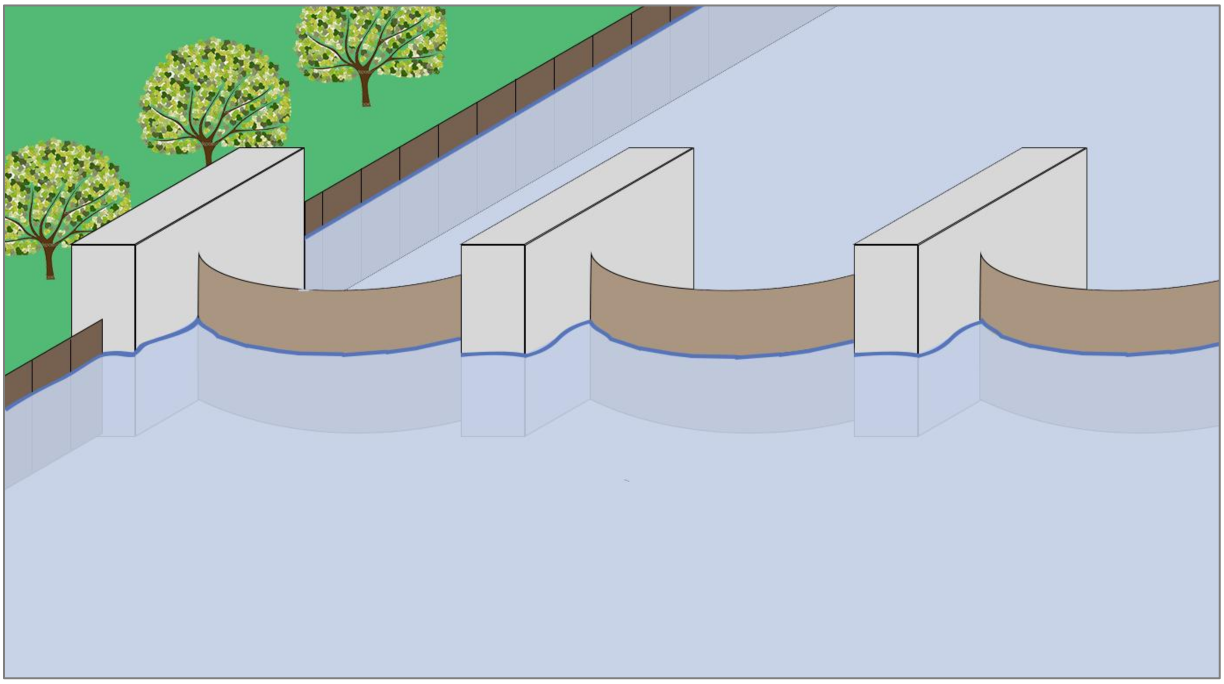


FIGURE 50: A SPATIAL REPRESENTATION OF OPTION 1.

A top view of this design is given in a map in Figure 51 and Figure 52. In this option the area just before the bifurcation is widened and a new bypass is constructed.

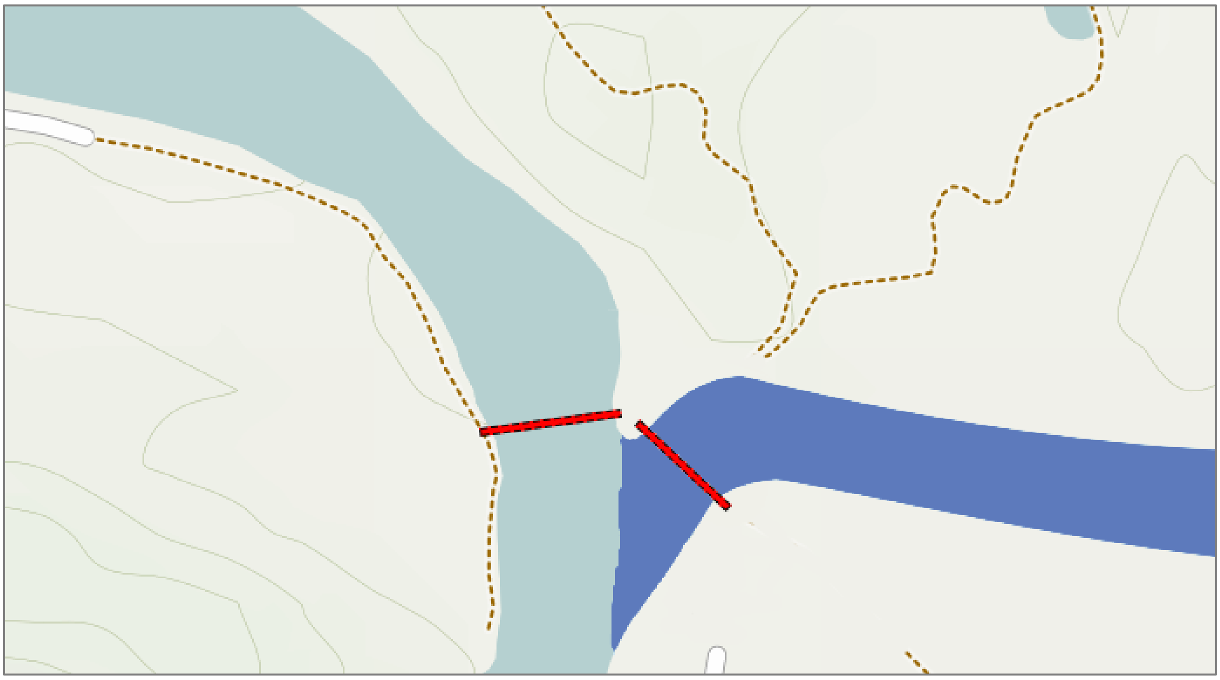


FIGURE 51: A MAP OF THE FIRST OPTION AT THE LOCATION OF BYPASS 1, THE NEW BYPASS CHANNEL IS SHOWN IN DARK BLUE

FIGURE 52: A MAP OF THE FIRST OPTION AT THE LOCATION OF BYPASS 2, THE NEW BYPASS CHANNEL IS SHOWN IN DARK BLUE

OPTION 2: MOVABLE WEIR

A moveable weir operating on the bottom of the river can also be used. Because the weir is adjustable in height, the discharge can be adjusted. A schematization is given in Figure 53. This option can be designed in the same way as option 1. Due to the absence of any head difference there are two constructions needed in both branches. See Figure 52.

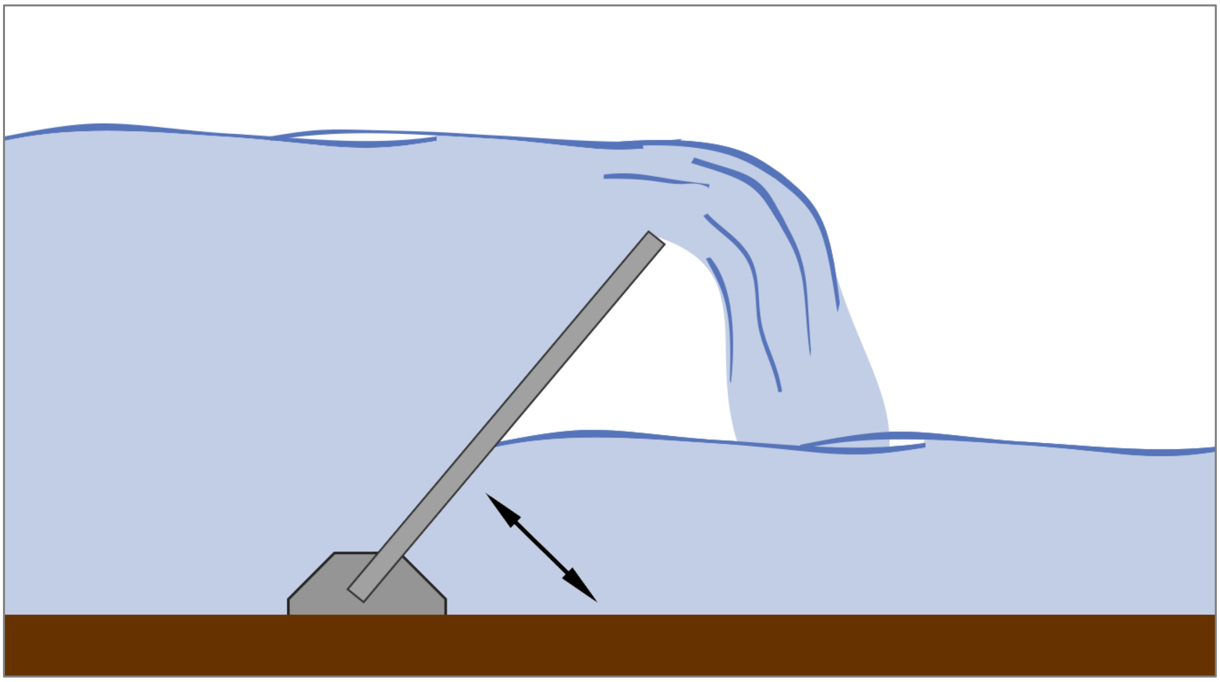


FIGURE 53: MOVABLE WEIR AT THE BOTTOM

OPTION 3: ROTATING GATE

The third option consists of a rotating gate. In an extreme situation, during extreme drought and extreme discharges, the gate can block one of the two branches completely, letting the water flow into the other branch. In normal situations the gate must be fixed at specific point in the river in order to be able to split the flow over the two branches. A spatial representation is given in Figure 54 and a schematization of the top view of the bifurcation to bypass 2 is given in Figure 55.

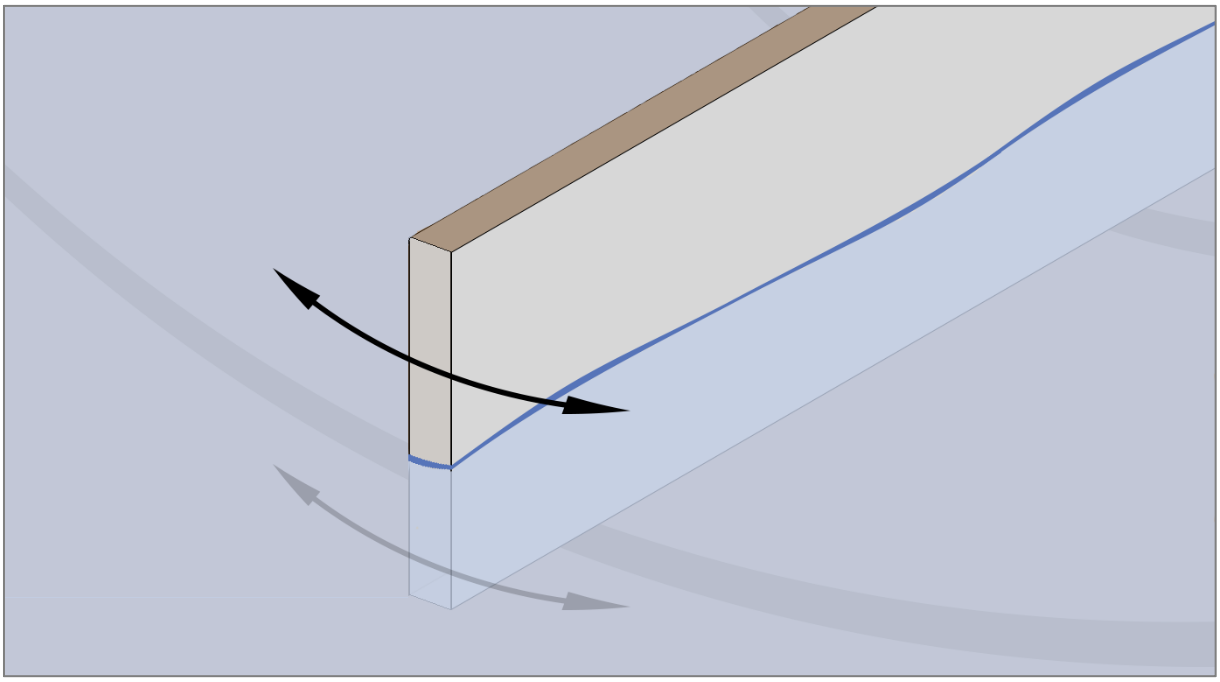


FIGURE 54: A SPATIAL SCHEMATIZATION OF OPTION 3

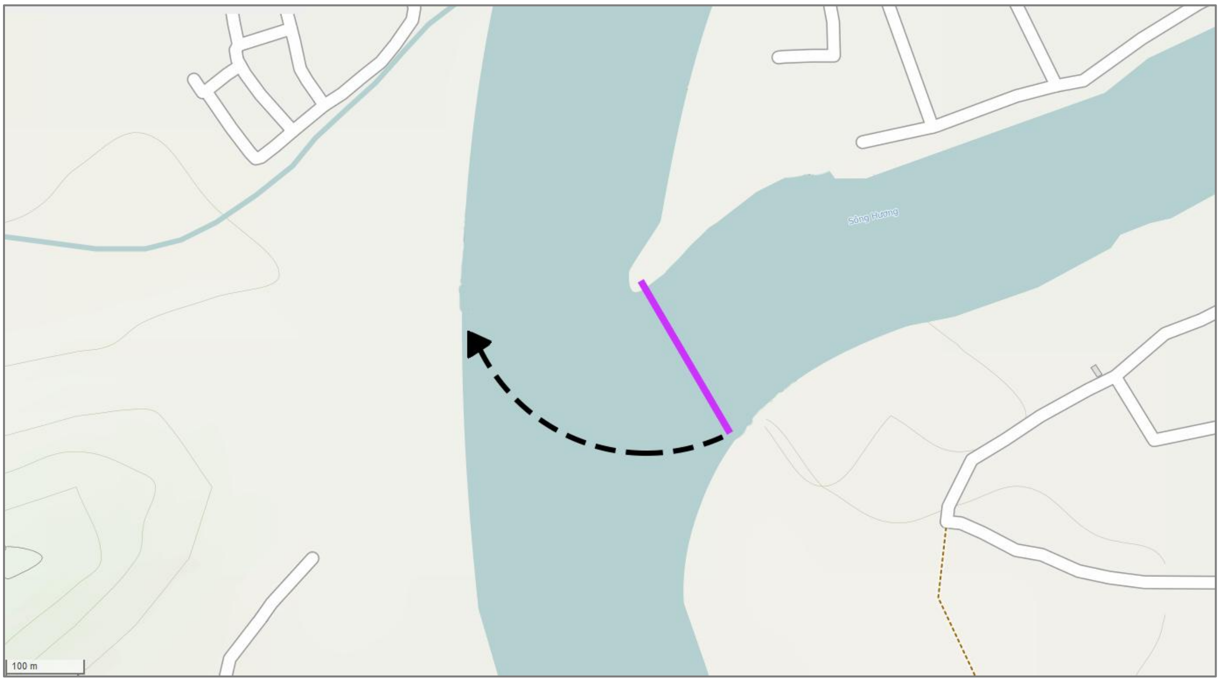


FIGURE 55: A TOP VIEW OF ROTATING GATE AT LOCATION 2

LEVEES

The hydraulic structures mentioned previously distribute the discharge over the multiple branches, apart from these solutions levees have to be built in order to prevent water flowing from the Huong River and bypasses overland. The height of the different levees will be determined by use of the SOBEK model.

SELECTION

In the previous paragraph three possible solutions have been discussed. The third option with a rotating gate is innovative but difficult to construct because of the large dimensions of the design. The gate needs a length of at least 300 meters in order to reach the other side of the river. Such lengths also require a large thickness of the gate in order to transfer all forces. This is also the case in extreme conditions when the gate closes off one of the branches. Big forces act on the gate which does not have intermediate supports that can transfer the forces from the structure to the foundation. The large size results in a large weight of the gate which implies that it is almost impossible to move. Combined with the fact that the river has a varying bottom profile it is very hard to implement this kind of solution.

Of the remaining two options, the second has its entire construction under water. This includes the engines to move the weir. This makes the first option easier to maintain. The varying bottom profile also creates a problem with the second option. Multiple weirs have to be installed next to each other each with difficult dimensions and there must be prevented that water can flow through an open area between the weirs.

From the above can be concluded that the first option is the most suitable one. Because the situations at the first and second bypass are comparable the first option can be implemented at both places.

3.1.2 COMBINATION 2: LAKE HUE

This section will give an introduction of Lake Hue. The volume of the reservoir will be calculated by defining the catchment area with the use of remote sensing data firstly. After this, the discharge into the reservoir will be determined with the use of the 20 year record of precipitation data and a unit hydrograph. Lastly, the needed volumes for Lake Hue is calculated by defining an operation strategy and model the reservoirs with the discharge that goes into the reservoir and the maximum output that was determined with SOBEK that can pass the dam into the Huong River without causing floods in the city of Hue.

INTRODUCTION OF LAKE HUE

A way to reduce the flooding of an area downstream is to store the water more upstream. In a natural situation this is also done by the trees and ground. But due to the absence of a master plan for the proper use of the land, as mentioned in the land use part of this report, the retention of water in the upstream areas is decreasing and this will lead to more problems downstream. The problems that are occurring include floods and droughts. A way to counteract these problems is by building reservoirs. In the Thua Thien-Hue province 5 major reservoirs are situated, see also Figure 56. The purpose of the most of the reservoirs is to supply water in the dry season and to store water during the rainy season. The rainy season last from the beginning of September till the end of December. The function of most of the reservoirs is to generate electricity, but other important functions are to counteract salt intrusion, flood control and store water for the dry season. Some information of all the reservoirs can be found in Table 8. Another report declared that the Binh Dien and Ta Trach reservoir store enough water to replenish the water shortage during the dry period (Neut, Zuylen et al. 2013). So, for the new reservoir this function can be removed. Other functions of this new reservoir are: the retention of water during the rainy season, the ability for boats to pass the dam and discharge management of the water. The new reservoir will be called Lake Hue.

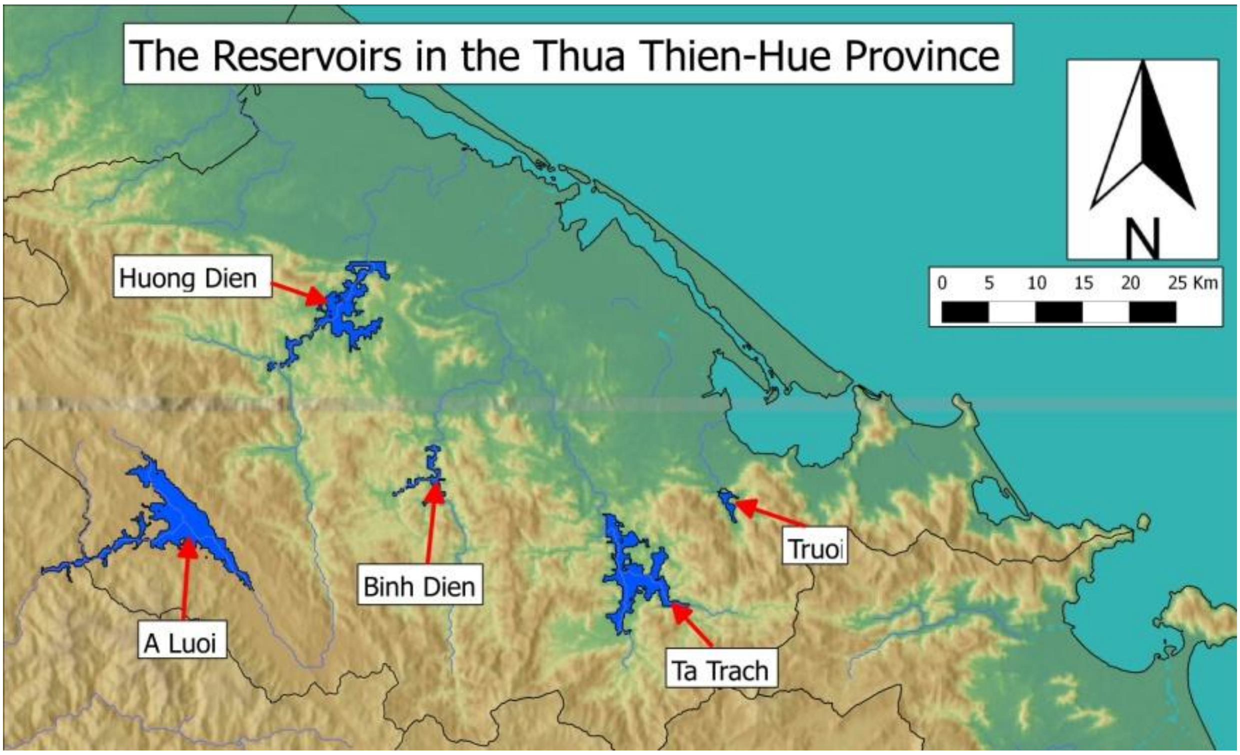


FIGURE 56: RESERVOIRS IN THE THUA THIEN-HUE PROVINCE

TABLE 8: THE CHARACTERISTICS OF THE RESERVOIRS (NARENCA 2012, NEUT, ZUYLEN ET AL. 2013)

Reservoir	Main Function	Volume [10^6 m^3]	Storage for Flood [10^6 m^3]	Dead Storage [10^6 m^3]	Maximum Electricity Generation [MW]
Huong Dien	Electricity	821	70	470	81
A Luoi	Electricity	60	No data	No data	170
Binh Dien	Electricity	344	70	79	44
Ta Trach	Flood Protection	646	436	210	20
Truoi	Water supply	55	No data	No data	6

The fact that it is not needed to store the water for the dry season makes it possible for the reservoir to be empty during the dry season and to only be filled when it is needed during the rainy season. Therefore, the character of this land is more like a retention area. It will store the water on the land only when it is needed during the rainy season and in the dry season this land can have an agricultural purpose. The houses that are located in the retention area must be relocated to a higher area. So an area must be chosen that is as sparsely populated as possible. This area will be sacrificed when the discharge of the Huong River becomes too large to protect the city of Hue. When this area is located downstream of Hue a very large canal or bypass must be created to transport a massive amount of water to the location where it can be stored. This will lead to a solution comparable to combination 1, namely retention areas with two bypasses to transport the water to these areas. To save costs a retention area can also be created upstream of Hue city, this will reduce the distance of transporting water. The water is stored closer from where it felt. Another advantage of storing the water in the upstream part of the river is the presence of the mountains. Fewer structures have to be built to create a retention

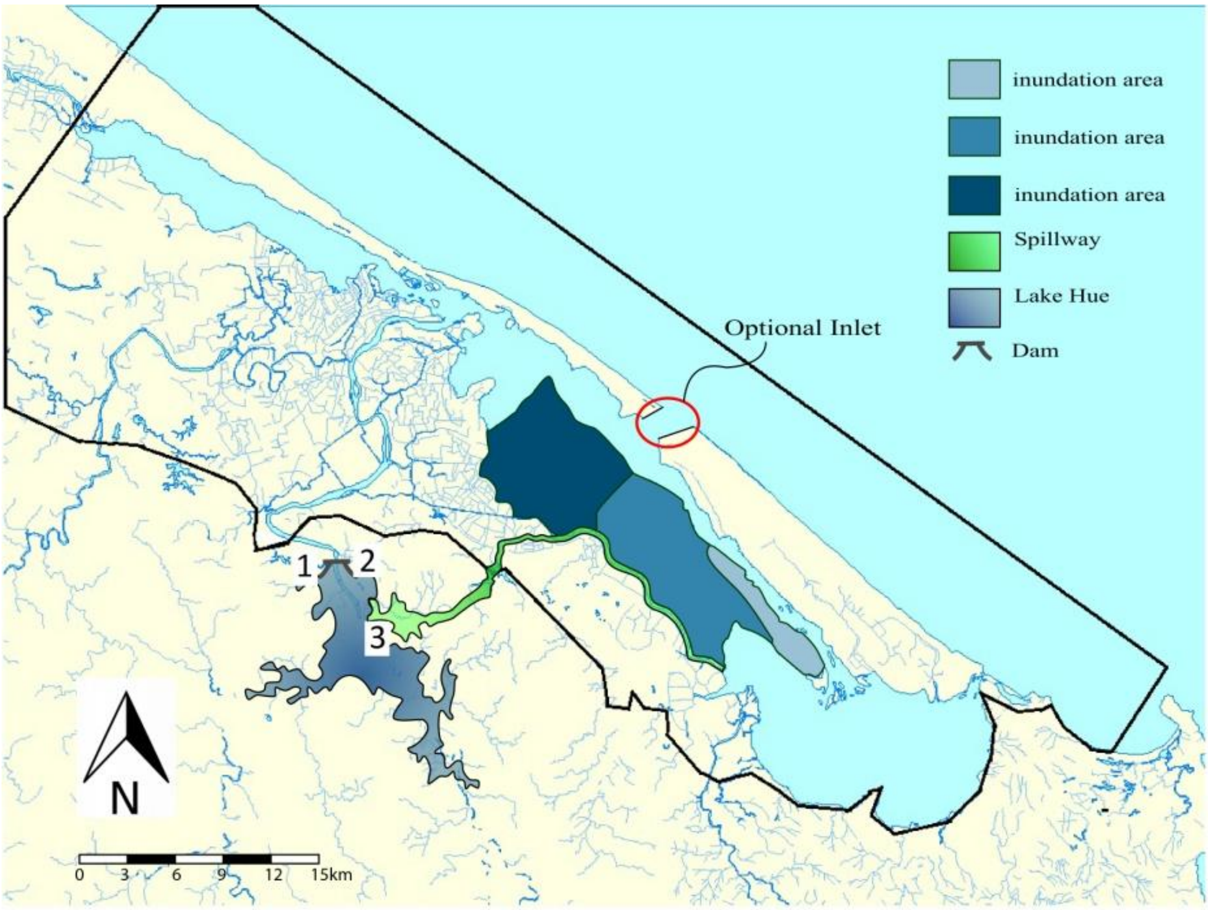


FIGURE 57: SKETCH OF LAKE HUE WITH THE PLACES OF THE IMPORTANT STRUCTURES: 1: CLOSURE DAM 2: WEIR/ORIFICE 3: EMERGENCY SPILLWAY

area, because the mountains can act as a dam. The only structures which should be built are a closure dam, orifice or weir, and some emergency spillways that can lead the water over the dam when the water becomes too high or if there is a risk of collapsing. The water from the spillway will flow towards the agricultural field, which will be inundated when the reservoirs and Lake Hue have no capacity any more to store the water. The agricultural field will be sacrificed in order to protect the city of Hue. In Figure 57 a sketch is given of the retention area and the spillways. There are 3 main constructions needed, namely the closure dam (see 1 in Figure 57), the orifice or weir in the closure dam to maintain a discharge over the dam into the Huong River when the closure dam is closed (see 2 in Figure 57), and the emergency spillway to let the water flow towards the agricultural fields which can be inundated when more storage is needed (see 3 in Figure 57). These constructions will be worked out in the design part of this chapter.

The closure dam will be closed when more than 500m^3/s goes through the river. This 500m^3/s follows from the SOBEK model. The model shows that the city of Hue will be flooded when 600m^3/s flows through the river. By letting 500m^3/s through the closure dam some tolerance is allowed for more water to enter the river before it flows through Hue, for example rainwater from the catchments downstream of the dam. With an orifice or a weir the 500m^3/s will still be released from the closed dam. The additional water will be stored in Lake Hue. When the capacity of Lake Hue is reached the emergency spillway will be put in use. The additional water will then be released through the emergency spillway in order to prevent the dam from collapsing. The spillway will connect the reservoir with the An Cu'u River to the northeast. The bypass, which connects the reservoir to the An Cu'u River, will get an approximate length of 11 kilometers of which 2.5 kilometer will flow through urban areas. The water will flow through a canal towards the lagoon. When this canal or the lagoon has no capacity anymore to store water, the water will be stored in the agricultural fields east from the city of Hue.

During the dry season the closure dam is open and the vessels can navigate over the river. When the closure dam is closed, they cannot navigate further than the closure dam. The navigability

when the dam is open must be further investigated to determine if it is feasible. This will be done later in this chapter.
The place of the closure dam must be on a strategic place, a wider closure dam will result in much higher cost. So a place where the canyon is very narrow is the best option. Also the mountains range must provide a good water barrier for Lake Hue, so only some additional walls have to be created. In Figure 58 the 20 meter contour line is shown. The place highlighted with the red line is the place where the canyon is the smallest. This place provides the ideal location for the closure dam in a geographical point of view. The orange line in Figure 58 shows the location of the spillway. This location is preferred, because not a lot of soil excavation is needed for the construction of this dam at this location.

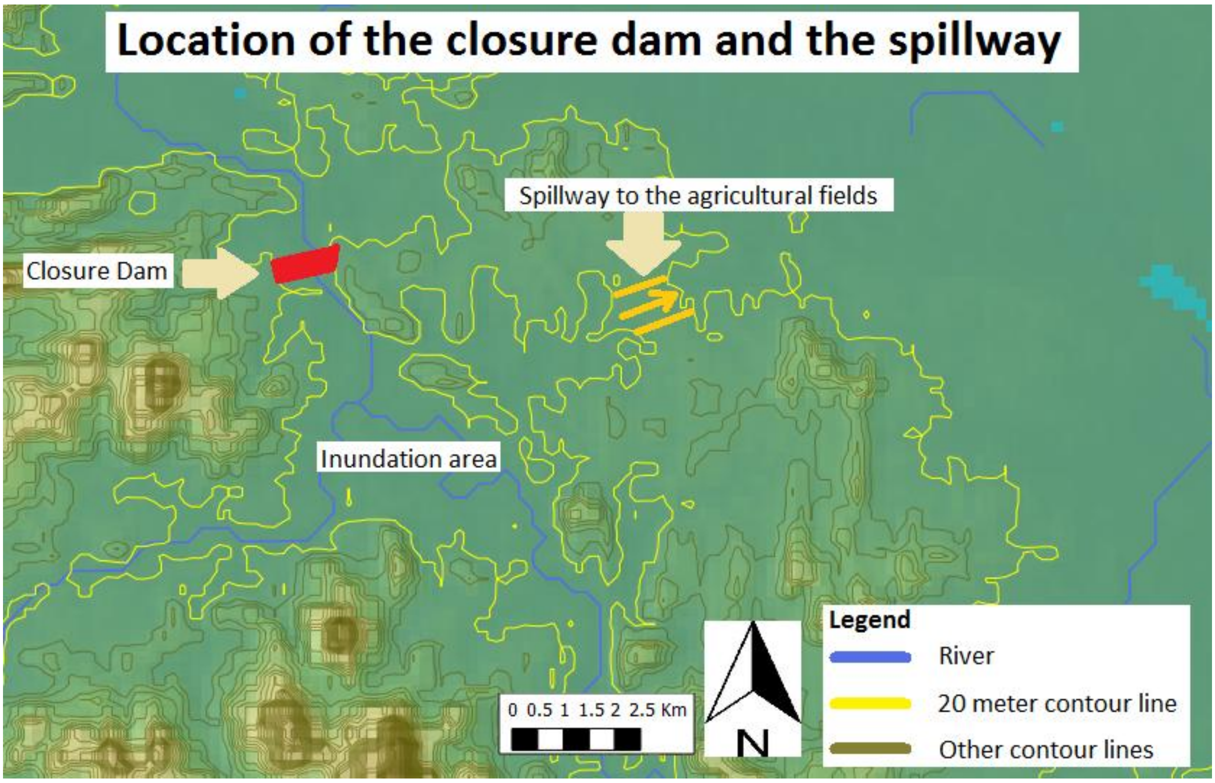


FIGURE 58: LOCATION OF THE CLOSURE DAM AND THE SPILLWAY

THE CATCHMENT AREA

The catchment area is the area that is drained by the river. By knowing the precipitation and the runoff coefficient and the unit hydrograph of the catchment, the discharge at that point of the river is known. First the catchment area is calculated with the use of remote sensing data. The approach is worked out in Appendix D. The Huong River is a confluence of the Ta Trach River and the Huu Trach River. The catchments of both rivers are shown in Figure 59.

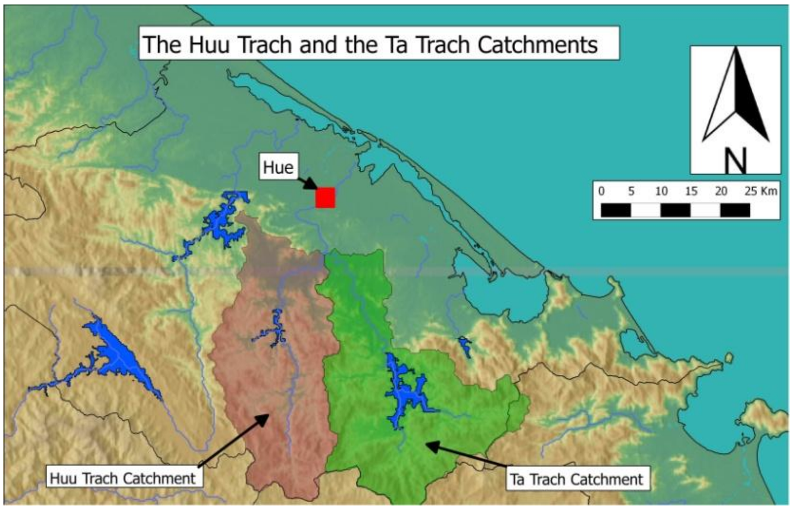
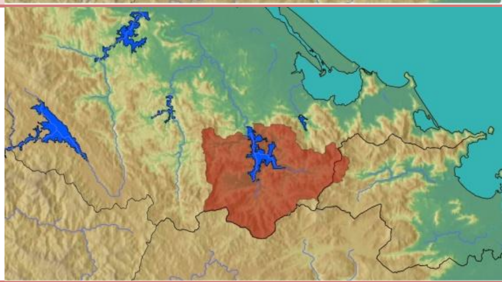
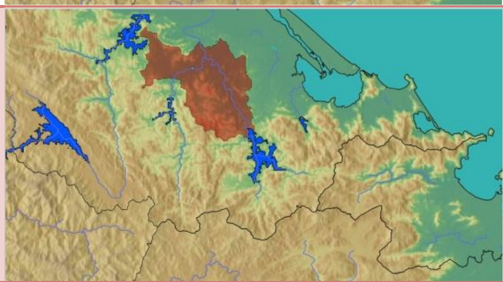


FIGURE 59: THE HUU TRACH AND THE TA TRACH CATCHMENTS FOUND WITH THE USE OF REMOTE SENSING DATA

The catchment areas are respectively 763km² and 679km². A reservoir is located upstream this confluence point in both rivers. In the Ta Trach River the Ta Trach reservoir is located and in the Huu Trach River the Binh Dien Reservoir. The catchment areas that are needed for this report, which are only the catchment areas of the reservoirs, Lake Hue, and the discharge measurement point, are given in Table 9. A more accurate estimation of the catchment area can be made by decreasing the amount of accumulated grid cells in Quantum GIS. But this would be time consuming, while the level of accuracy of the other assumptions is much lower.

TABLE 9: CATCHMENT AREA FOUND WITH THE USE OF REMOTE SENSING DATA

Catchment of the ……	Catchment	Catchment Area [km²]
Binh Dien Reservoir		520
Ta Trach Reservoir		581
Lake Hue		375
Discharge Measurement Point		200

Before the dimensions of the reservoirs can be estimated, one needs to look at the local climate in this province. Not a lot of data is available for this area, so more assumptions have to be made. The only available rainfall data are the Huu Trach and the Ta Trach rainfall stations from the period 1980-1999. With this data, estimation is made about the needed dimensions of Lake Hue.

RAINWATER RUNOFF

To translate the precipitation data into discharge data, some transformations must be done. In total 2 transformations are done in this report. The first one will correct for the water "losses". Not all the precipitation will end up in the river; this is due to the transpiration and evaporation.

To know the ratio between precipitation and losses, a water balance is made for a part of the Ta Trach catchment. In the Ta Trach catchment a single discharge measurement data is available for the period of 1981 till 1999. This data is received from the Hydrological Center in Hue. This discharge measurement point is called Thuong Nhat and is located upstream the Ta Trach Reservoir. With Quatum GIS the catchment area for this measurement point is determined. This is also shown in Table 9. The water balance consists of the precipitation as input and the discharge and losses as output. The difference of those fluxes is the storage within the boundaries.

An assumption is made that the storage in the start and the end of the rainy season can be neglected. This is reasonable because the total amount of storage is much lower than the four months sum of the fluxes. Furthermore, the storage is also a kind of loss in the rainy season and a released flux in the dry season. This makes the difference in storage zero, now the water balance consist of only a loss flux, precipitation flux and discharge flux. The rainfall input data is from the Ta Trach rainfall measurement point called Thuong Nhat and it is assumed that this rainfall data is representative for the whole catchment of the discharge measurement point. Only the rain and discharge data for the rainy season is used, because this is also the period in which Lake Hue is needed.

By transferring the daily rainfall data by multiplying the rainfall data with the catchment area, one gets the total amount of water that flows into the catchment. The output is calculated by multiplying the daily discharge (in cubic meters per second) with the amount of seconds in one day. Now, the input and output of cubic meters of water can be summarized, this is shown in Figure 60. The difference must be the water losses, because this is the only flux left in the water balance. This results in an average runoff coefficient of 0.8 in the rainy season. In the start of the rainy season this runoff coefficient is 0.78, but due to the decreasing storage capacity of the ground and vegetation during the rainy season because of saturation, this runoff coefficient increases to 0.82 for the end of the rainy season. Due to a lack of available discharge data only the runoff coefficient for this small section of the total area can be determined. Because the characteristics in vegetation and land use of the 200km^2 catchment of the discharge measurement are the same as the whole catchment of Lake Hue, Ta Trach and Huu Trach, one can assume that this runoff coefficient is the same for the three whole catchments that covers a total area of 1476km^2.

This first transformation results in an assumption that a runoff coefficient of 0.8 is representative for the whole Huu Trach, Ta Trach and Lake Hue Catchments. So the effective rainfall that is drained by the rivers and eventually ends up in the reservoirs is 80% of the total rainfall.

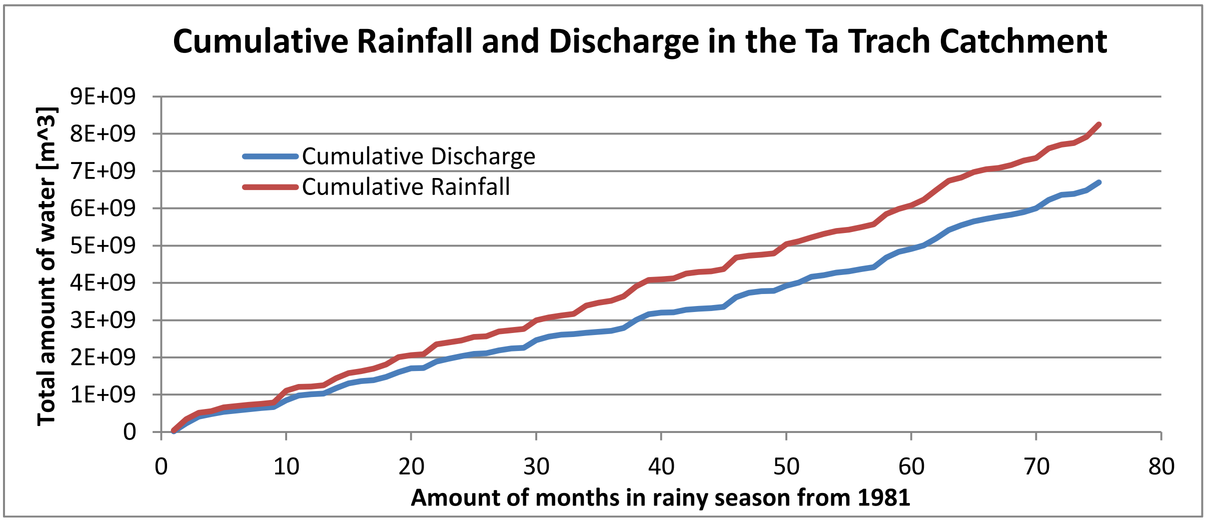


FIGURE 60: THE CUMULATIVE RAINFALL AND DISCHARGE FLUX IN CUBIC METERS PER SECOND FROM THE PERIOD 1981 TILL 1999

The second transformation corrects for the time of arriving into the reservoir. A unit hydrograph is made for the same catchment area as the area of the previous transformation, because this is the only point in this river where the discharge is measured. The unit hydrograph corrects among other things, for the geography. If the area is larger, the time of arriving in the reservoir is also increasing. Also the shape of the catchment is important. The unit hydrograph of a stretched catchment is different than a circular catchment with the same surface area. Furthermore, the unit hydrograph corrects for the different paths that the water can take. The water can fall directly in the river, but it can also fall on the land surface and percolate into the ground. For the last mentioned, the time of arrival will be larger. In the wet season this effect is less, because the soil is completely saturated. But still, one has to include this effect.
This effect can be modelled with the use of a unit hydrograph. A unit hydrograph shows which part of the precipitation of a single day arrives as an output at the boundary or in this case the discharge measurement point. The only discharge data that is available is the data from Thuong Nhat, which has a small catchment area of 200km². The assumption is made that the unit hydrograph corresponding from this catchment is comparative with the unit hydrograph for the whole Lake Hue, Ta Trach and Huu Trach catchments. This is not completely true, because the catchment of the discharge measuring station is very small and therefore not fully comparative with the whole catchment areas, which has a volume of 1476km². But this is the most reasonable unit hydrograph for the lack of availability of the data. The upscaling of the area will result in an increasing spread of the unit hydrograph. So by assuming that the small area has the same unit hydrograph as the whole catchment will result in a "safe" unit hydrograph, so more than in reality flows into the reservoir on the first day. In reality the unit for the first day is probably lower, which result in more spreading of an extreme rain event.
To get the unit hydrograph, the measured discharge is approached as good as possible with the precipitation data without losses. Especially the peaks are of most importance, because they will result in the filling up of the reservoirs. The discharge data of 1995 is used to calibrate the unit hydrograph. The best fit between the approached discharge and the measured discharge is shown in Figure 61. The resulting unit hydrograph is shown in Figure 62.

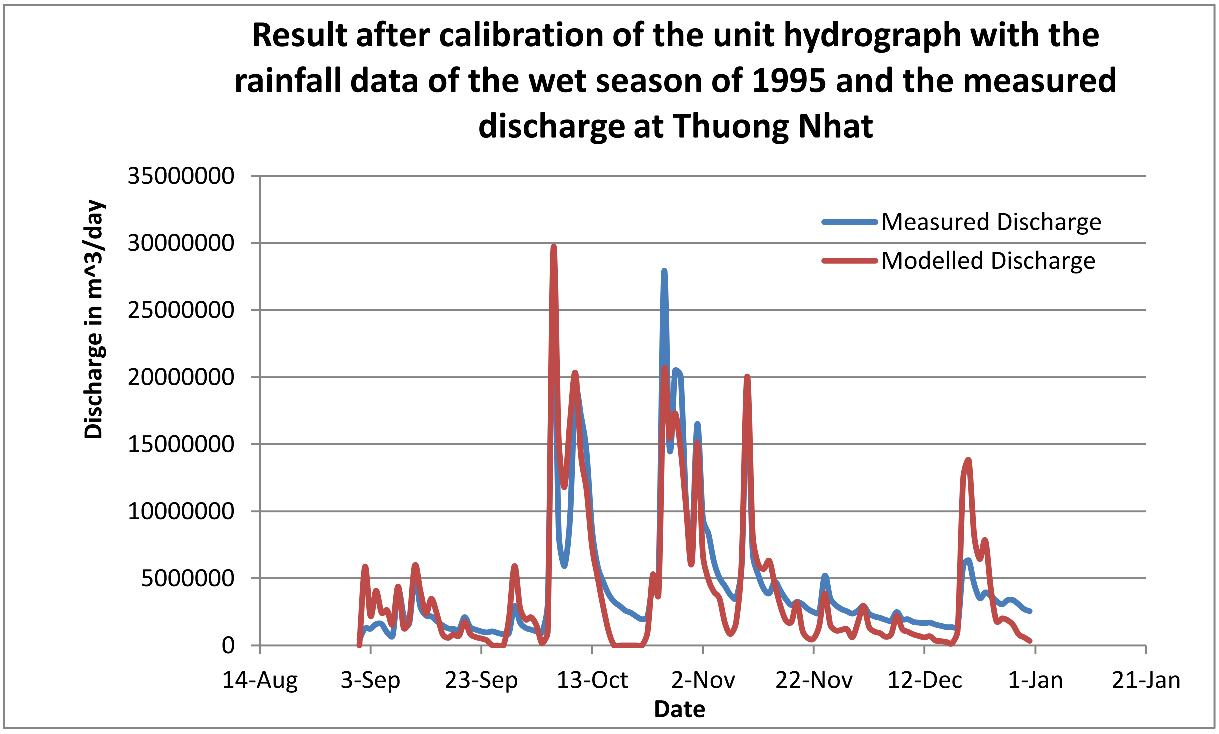


FIGURE 61: RESULT AFTER THE CALIBRATION OF THE UNIT HYDROGRAPH WITH THE RAINFALL DATA OF THE WET SEASON OF 1995 AND THE MEASURED DISCHARGE AT THUONG NHAT

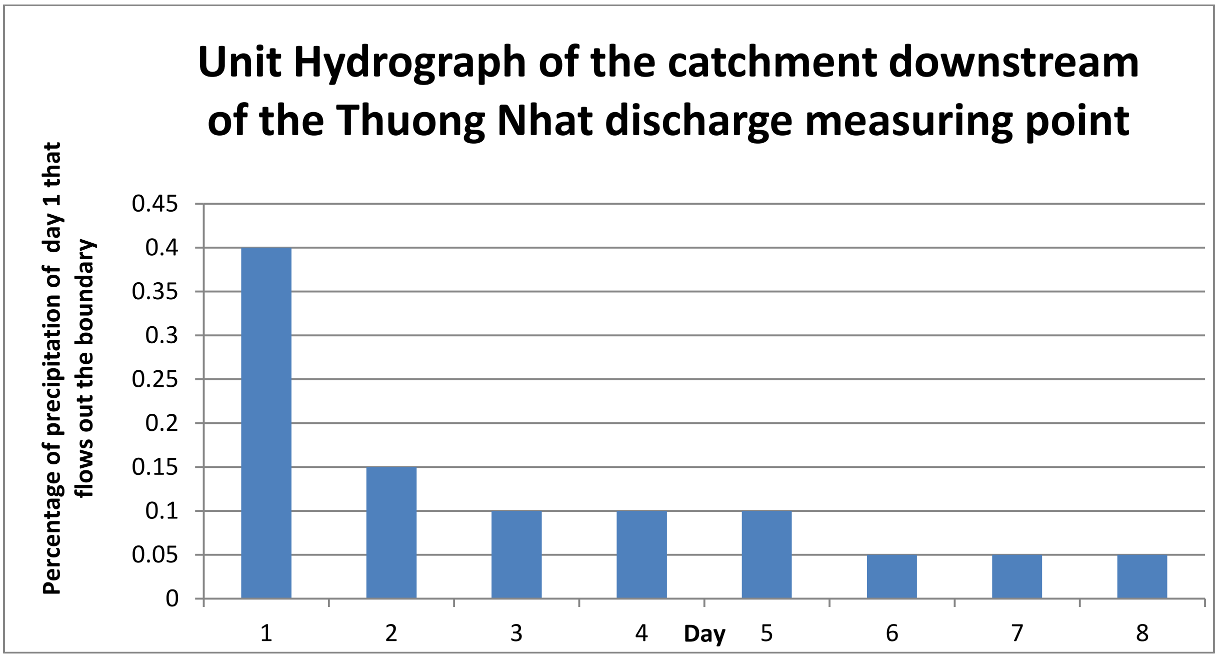


FIGURE 62: THE UNIT HYDROGRAPH OF THE CATCHMENT DOWNSTREAM OF THE THUONG NHAT DISCHARGE MEASURING POINT

The wet season of 1985 is used to verify the unit hydrograph; this result is shown in Figure 63. One can see that the modelled discharge peaks with the unit hydrograph are good corresponding with the measured discharge for 1995 and 1985. So this unit hydrograph is very suitable for this catchment.

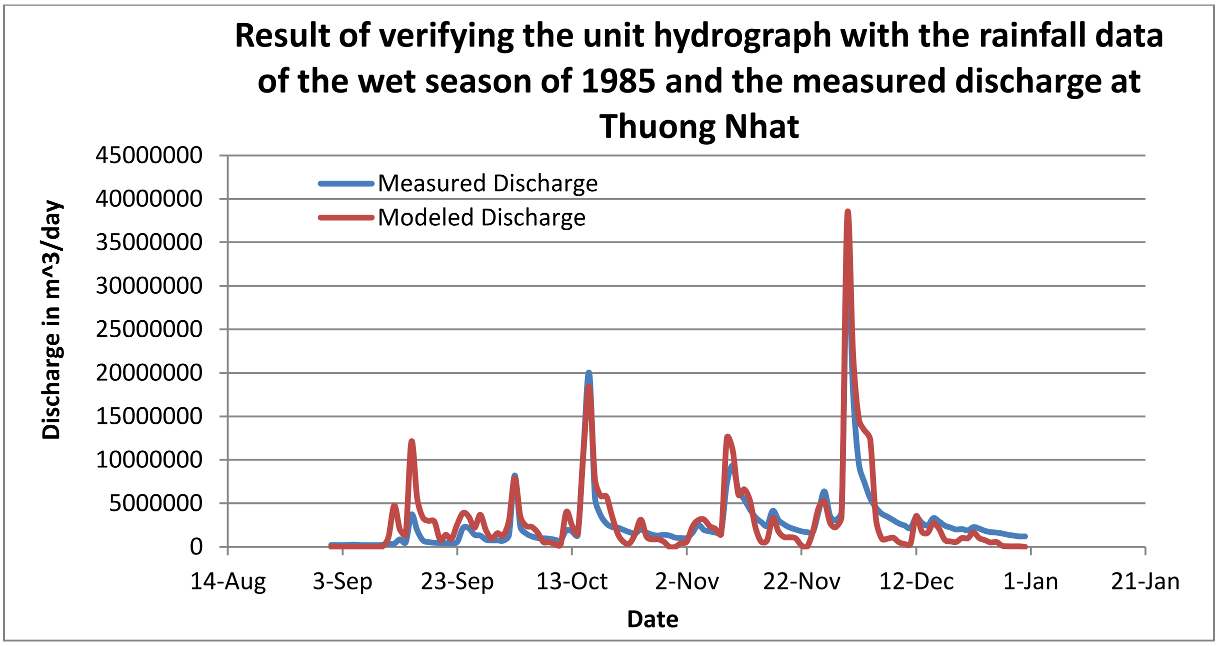


FIGURE 63: VERIFYING THE UNIT HYDROGRAPH WITH THE RAINFALL DATA OF THE WET SEASON OF 1985 AND THE MEASURED DISCHARGE AT THUONG NHAT

Because of the lack of measurements in discharge and rainfall data, a couple of assumptions have to be made. First, the rainfall measured in Ta Trach and Binh Dien measurement stations are representative for respectively the whole Ta Trach and Huu Trach catchment. Secondly, due to the lack of rainfall data of the Lake Hue catchment, this catchment will get the average precipitation of the Ta Trach and Binh Dien rainfall measurement stations. Thirdly, the loss coefficient is the same for the whole catchment. Fourthly, the unit hydrograph is representative for the whole catchment.

SIMULATING LAKE HUE WITH THE AVAILABLE RAINFALL DATA

The model is schematically visualized in Figure 64. The maximum discharge that can pass the closure dam is 500m³/s. The flood storage of Binh Dien and Ta Trach reservoirs are 70 million and 435.6 million m³ respectively.

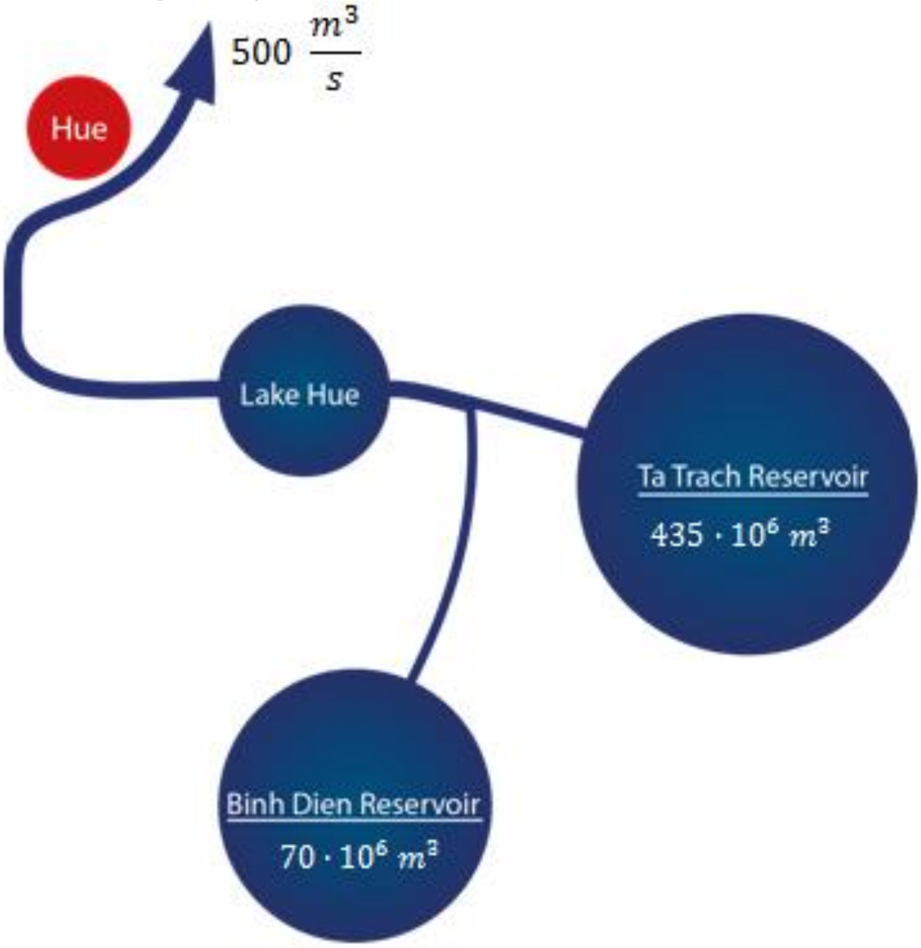


FIGURE 64: THE VISUALIZED MODEL WITH THE THREE RESERVOIRS

To simulate the Lake Hue Reservoir, one needs to define the strategy of the reservoirs. The chosen strategy is to fill Lake Hue as late as possible. The maximum amount of water that can flow through the dam into the Huong River is 500m³/s. First, the rainwater which falls in the catchment of Lake Hue has the priority to flow through the closure dam, because this water has no flood storage when Lake Hue is not yet in operation. Secondly, the water that falls in the Huu Trach catchment can flow through the dam. This is because the Binh Dien Reservoir has the lowest capacity for water storage. After those two catchments, the Ta Trach catchment can get rid of the water that falls in his catchment when there is enough capacity left in the Huong River. Furthermore, when the reservoirs use their water storage capacity, the Binh Dien reservoir can dump the water firstly if it possible. This reservoir gets the priority because the storage capacity is much less than the Ta Trach Reservoir. When the storage capacities of the reservoirs are full and more than 500m³/s passes the dam the closure dam will be closed and Lake Hue will be filled.

For the reservoir routing this strategy is used in an excel file. Lake Hue is modelled for 20 rain seasons with the measured precipitation data from 1979 till 1999. The run off coefficient and the unit hydrograph as determined before are used to transform the rainfall data into discharge data. The needed volume for Lake Hue for each year that was needed to keep the maximum discharge after the closure dam 500m³/s are shown in Figure 65. The days that Lake Hue is in operation, so the area is partly or completely filled with water is shown in Figure 66.

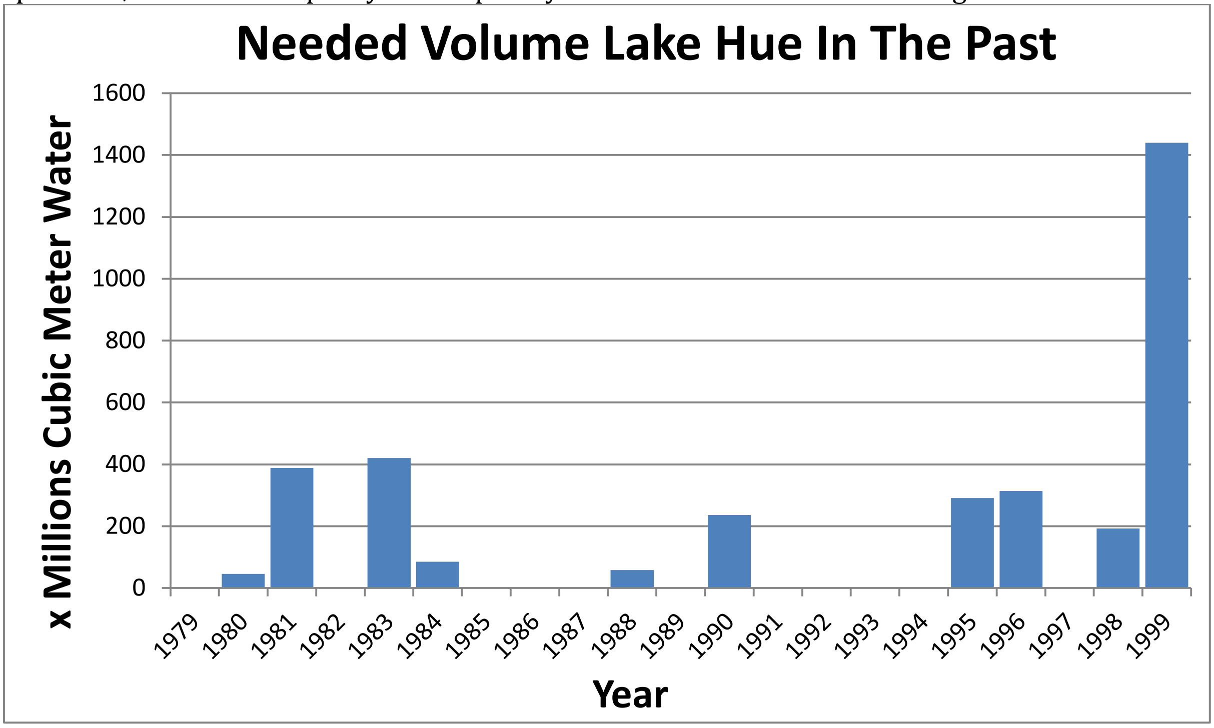


FIGURE 65: NEEDED STORAGE CAPACITY OF LAKE HUE WHEN 20 YEARS OF RAINFALL DATA IS USED FOR MODELING

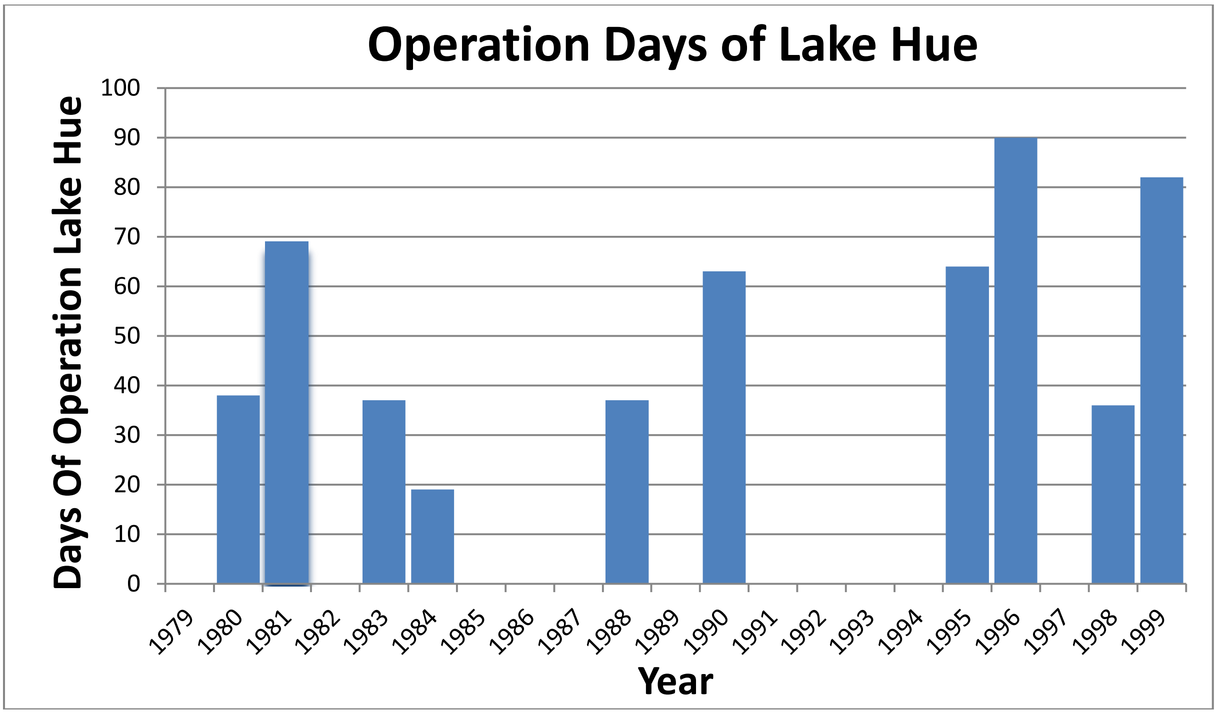


FIGURE 66: OPERATION DAYS OF LAKE HUE WHEN 20 YEARS OF RAINFALL DATA IS USED FOR MODELING

The Ta Trach and Binh Dien reservoir have already led for dampening of the higher rainfall events. If one looks at the history of the water level at the Kim Long station, than one cannot translate the highest water level measured in the Kim Long station to the highest needed volume for Lake Hue. There is a simple explanation for this. The water level as measured in the past was rising by one single rain event, whereas now more rain events are needed to fill up the storage capacity first. So the heaviest rainfall event will not cause the highest river level in Hue, but the rainfall events before this heavy rainfall event are also important. If it was dry before this heavy rainfall event, than the storage capacity is still empty and the water level in Hue will be lower than if the heavy rainfall event was after a wet period when the storage was already full.

DETERMINING THE VOLUME FOR LAKE HUE

The last step is to determine the volume of Lake Hue. When one wants to store all the water of 1999 a massive closure dam is needed and also the mountains around the lake are not high enough to enclose the water. The mountains around Lake Hue are completely closed when the height of the closure dam is 22 meters or lower. If the dam needs to be higher more dams and structures need to be built than the closure dam only. In Table 10 the height of the dam and the volume of Lake Hue are calculated with Quantum GIS and an elevation map. From the model twenty needed volumes were calculated and also shown in Figure 65. By making a Gumbel distribution from these values one can see which return period has a certain volume. The Gumbel distribution is shown in Figure 67. From the linear fit the return period is calculated and given in Table 10.

TABLE 10: STORAGE CAPACITY WITH DIFFERENT CLOSURE DAM HEIGHTS

Height of the Closure Dam	Storage Capacity determined with remote sensing	Return Period in years
17	168417562	3.259801
18	207406831	4.072765
19	249611709	5.182778
20	297283124	6.80446

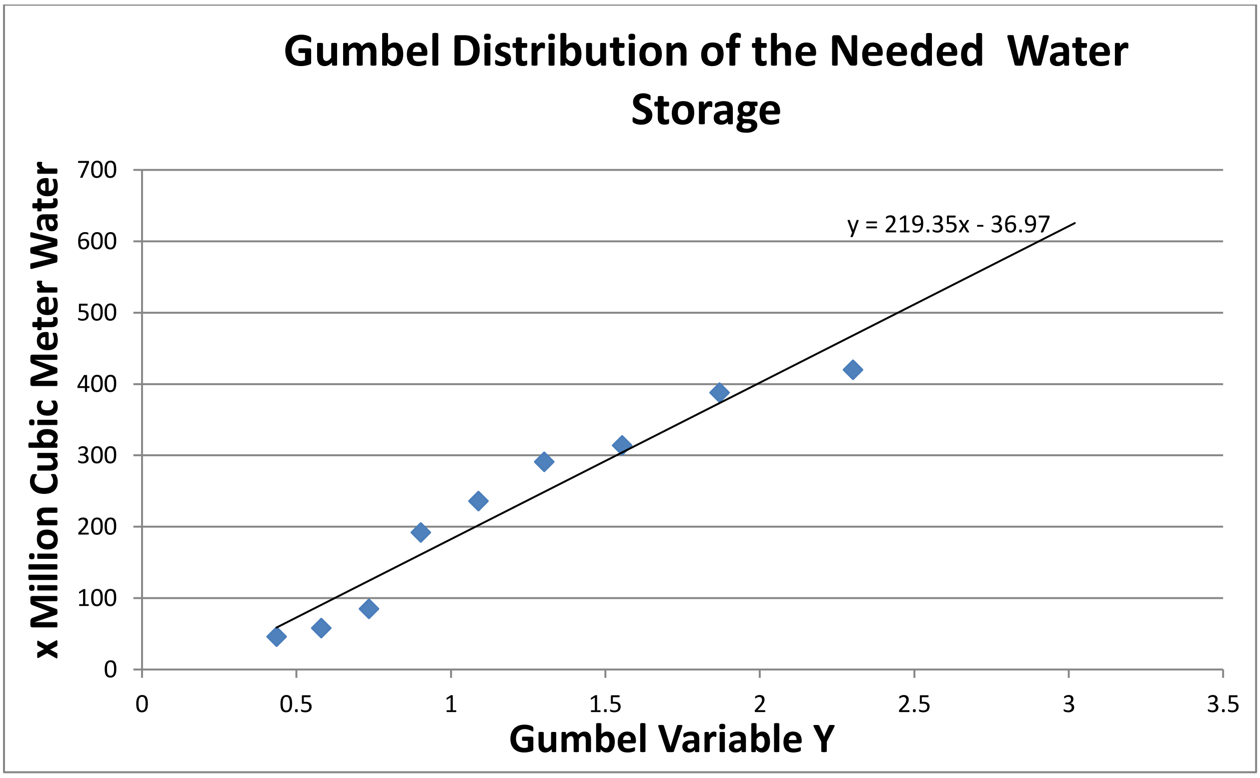


FIGURE 67: GUMBEL DISTRIBUTION OF THE NEEDED WATER STORAGE IN WHICH THE GUMBEL VARIABLE Y IS DEFINED AS –LN(-LN(1-1/T)) IN WHICH T IS THE RETURN PERIOD

The agricultural land highlighted in Figure 57 will be used as inundation zone if more storage of water is needed. The water will flow over the spillway and will flow through the channel to the lagoon. When the lagoon has a high water level and cannot store more water the inundation zone must be used. The current return period of this inundation land is once in five years, see figure Figure 36. It would be preferred if this spillway and channel would be used once in the five years, resulting that the water can always flow over the spillway and be stored in the inundation zone, so not depending on the height of the water level in the lagoon. Furthermore, the inundation zone with a return period of 2 years is not needed anymore, so downgrading of this area is not needed. This criteria result to a closure dam with a height of 19 meters. The result is a spillway that is used with a return period of 5.1 years.
The closure dam of Lake Hue will not be closed every year. From the model with 20 rain seasons, it turned out that the return period of Lake Hue will be 2 years.
Lake Hue was too small for 5 rain events. These were the rain events of 1981, 1983, 1995, 1996 and 1999. In those rain events the spillway will be used. The maximum discharges of the spillway and the number of days that the spillway is used are given in Table 11.

TABLE 11: THE NEEDED VOLUME AND MAXIMUM SPILLWAY DISCHARGE IN LAKE HUE

Year	Needed Volume in lake Hue in m^3	Maximum Discharge Spillway in m^3/s	Amount of Days that the Spillway is used
1981	388.000.000	518	6
1983	420.000.000	1042	5
1995	291.000.000	194	4
1996	314.000.000	234	4
1999	1.440.000.000	4643	9

IMPLEMENTATION OF LAKE HUE

FIGURE 68: THE CURRENT BRIDGE OF THE MAIN ROAD WHICH IS LOCATED INSIDE LAKE HUE

Lake Hue will have a closure dam of 19 meters high (height without safety factors), and the total volume when it is completely filled will be 250 million cubic meter. The Lake is shown in Figure 69. The land upstream of the closure dam must be reorganized. A lot of people have to relocate to higher places and roads must be replaced. The land can still be used in the summer for agricultural purposes. A research must be done at the fertility of the ground when in some rainy seasons 19 meter water is located on top of the agricultural fields. Also one of the most important highways flows through this area. But the bridge over this area is not 19 meters above mean sea level, see Figure 68. This road must be incremented, so it is possible to drive over this bridge when Lake Hue is filled. This is very important, because it is one of the main roads (TL1) when the people have to evacuate the coastal plain. Another possibility is to build the new road on top of the dam, which will also be located at this place. An impression of Lake Hue is given in Figure 70.
The dam is only in operation when it is needed. So the dam influences the environment only some days per year.

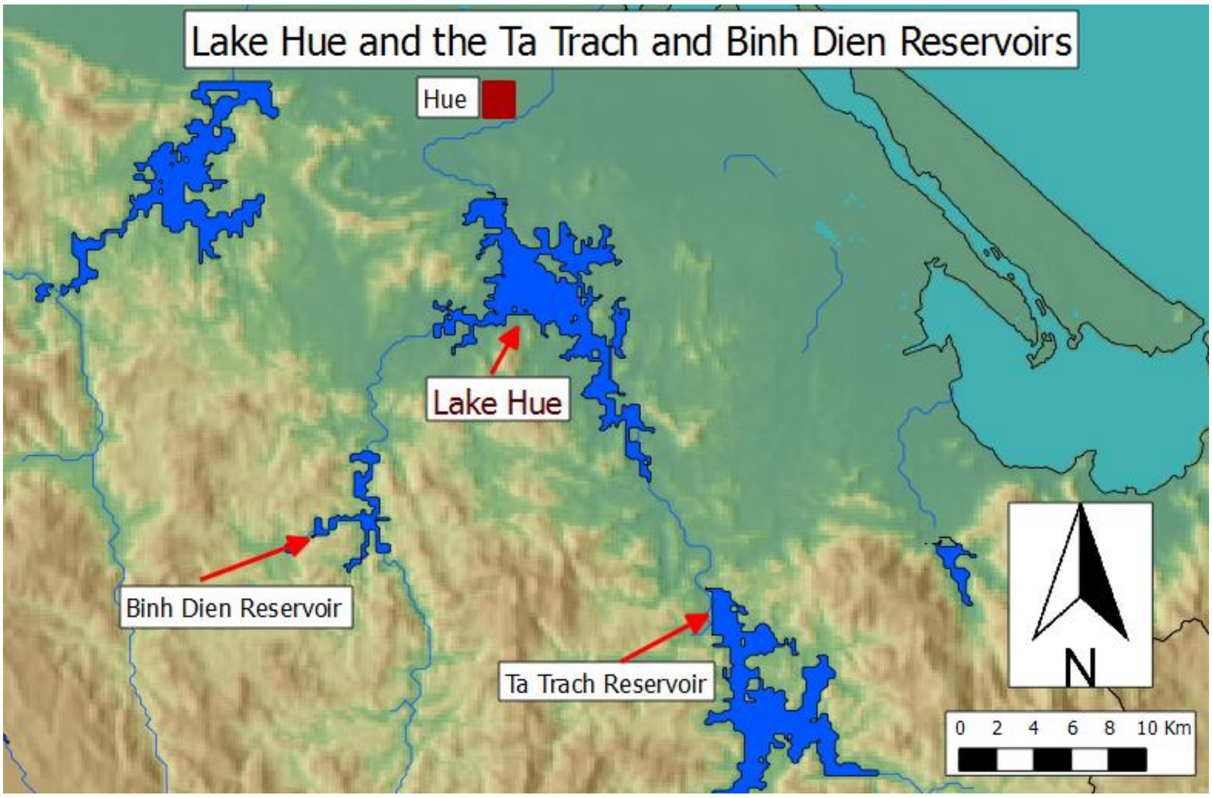


FIGURE 69: THE NEW RETENTION AREA LAKE HUE AND THE TWO CURRENT RESERVOIRS TA TRACH AND BINH DIEN

For this research some remarks have to be made. Firstly, the estimation of the height is based on rough assumptions due to the lake of discharge and precipitation data in the area. Also for the making of the unit hydrograph it is better to have a discharge measurement at the reservoir; this will result in a more accurate unit hydrograph. Secondly, the data series used for the reservoir routing only consist of 20 years precipitation data. More years are needed to get a better estimation of the return periods. For the return periods the 1999 rain season could not be included, because this was a once in a 100 year storm. When this was included in a 20 year long time series this storm would be underestimated, which in the end can lead to an over dimensioned design. Thirdly, not only the Huong River can cause flooding in Hue, but also the Bo River North of Hue. A research can be done to investigate how large the flooding capacity must be of the Huong Dien Reservoir in order to prevent the city of Hue from flooding with the desired return period.

FIGURE 70: THE PLACE WHERE LAKE HUE WILL BE SITUATED AND AN IMPRESSION OF LAKE HUE WHEN IT IS IN OPERATION

3.1.3 MODELLING THE COMBINATIONS WITH SOBEK

The model discussed before is used to examine potential measures against the flooding in the Hue province. The 2 scenarios that appeared most promising are modelled and discussed. But before this can be done, the measures that have already been constructed or are being constructed, need to be modelled. These measures are the Reservoirs Huong Dien, Binh Dien and Ta Trach (under construction and in operation in 2014).

RESERVOIRS IN THE SOBEK MODEL

The model as described earlier does not yet incorporate the reservoirs that are now located in the area. Three reservoirs that discharge directly into the 2 major rivers in the area, the Huong River and Bo River, are taken into account. These reservoirs are the Huong Dien, the Binh Dien and the Ta Trach reservoirs. The Huong Dien reservoir is located in the Bo River. The other two reservoirs are located in the Huu Trach and Ta Trach rivers respectively, which are tributaries of the Huong River.

The volume that is reserved for flood control differs between the reservoirs. The Huong Dien and Binh Dien reservoirs are constructed with the purpose of production of hydropower, while the Ta Trach is purpose built for flood control. This is seen in the 435,6 million cubic meters that is available, compared to the 70 cubic meters available in the Huong Dien and Binh Dien reservoirs (Neut, Zuylen et al. 2013).

When the discharge data provided with the SOBEK model is considered, the reserved volume is not enough to reduce the discharge to safe values. It is difficult to determine the actual operational control that would have been used at the time of the simulated flooding. Therefore, it is assumed that the available volume is used to reduce the peak discharge. Figure 71, Figure 72 and Figure 73 show the resulting discharges into the respective rivers before and after the construction of the reservoirs.

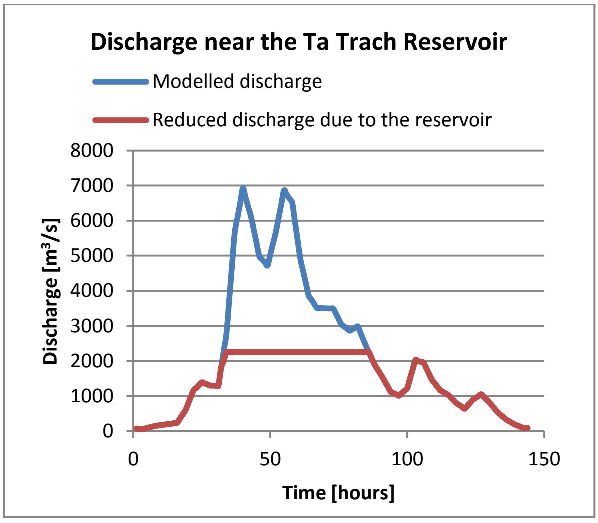


FIGURE 71: DISCHARGE IN THE TA TRACH RIVER BEFORE AND AFTER CONSTRUCTION OF THE TA TRACH RESERVOIR

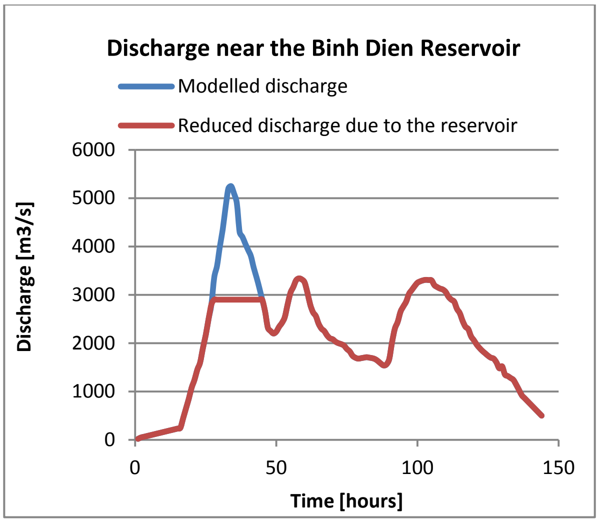


FIGURE 72: DISCHARGE INTO THE HUU TRACH RIVER BEFORE AND AFTER THE CONSTRUCTION OF THE BINH DIEN RESERVOIR

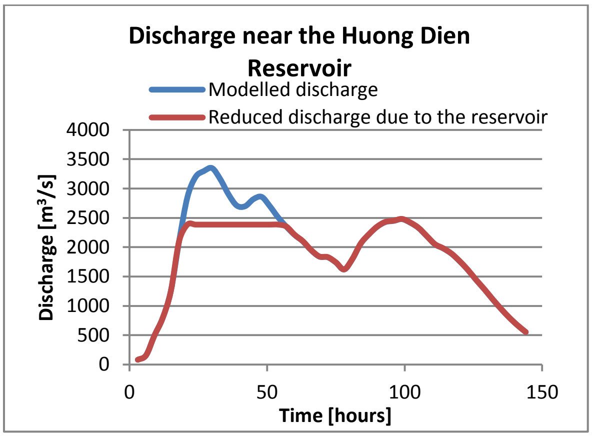


FIGURE 73: DISCHARGE INTO THE BO RIVER BEFORE AND AFTER THE CONSTRUCTION OF THE HUONG DIEN RESERVOIR

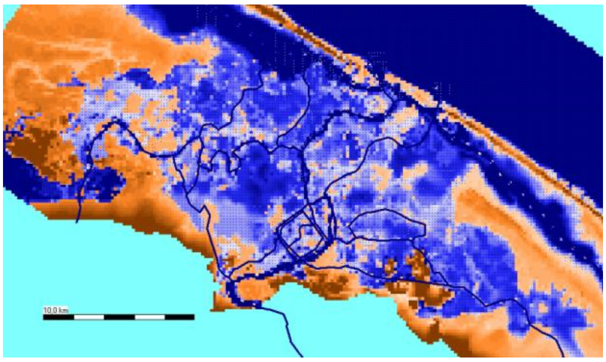


FIGURE 74: MODELLED FLOODING FOR A ONCE IN 5 YEAR EVENT AFTER THE CONSTRUCTION OF THE HUONG DIEN, BINH DIEN AND TA TRACH RESERVOIRS

RESULTS

Modelling the flooding that would have occurred if the reservoirs had been constructed at the time of the modelled flooding, allows us to compare the different scenarios and their value. Figure 74 indicates that the flooding still occurs in most areas. Some small differences can be seen, especially near Hue City, where the shade of blue seems a bit lighter. The water level at the Kim Long measuring station has been reduced slightly during the period where water is retained in the reservoirs. The water level was 4.3 meters, now it is 3.65 meters above mean sea level. This does however still result in severe flooding.

SCENARIO 1: THE DOUBLE BYPASS

THE WESTERN BYPASS

The western bypass uses existing streams to divert the excess water around the City of Hue. These streams need to be reinforced to be able to cope with the extra discharge. The network lay-out that is used to model the area in SOBEK does not change, only the cross-sections of the stream are changed. To ensure enough diverted water, 2 control structures are needed. One control structure limits the flow through the Huong River, and the other closes the small stream that runs parallel to the Huong River. This prevents an unwanted redirection to the city. The highlighted reaches in Figure 75 are changed to cope with higher discharges. This is done by increasing the height of the top of the cross sections. The new cross-sections have bank levels ranging from 6 meters above mean sea level in the downstream area, to 12 meters near the start of the bypass. Originally, it was 2 and 5 meters respectively.

THE EASTERN BYPASS

The eastern bypass starts just below the confluence point of the Ta Trach and Huu Trach River. A canal, leading away from Hue City through the higher elevated land diverts the water. A control structure in the Huong River, just downstream from the bypass limits the water flowing into the Huong River. As a result of the increased discharges towards the inundation area in the east, additional protection against the high water levels is necessary at its western boundary. This keeps water from flooding Hue City from the east.

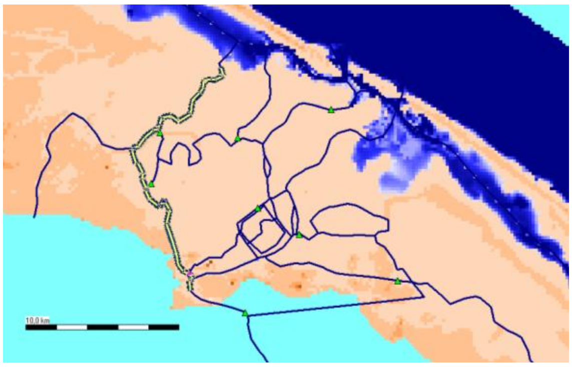


FIGURE 75: SOBEK NETWORK WITH THE MODIFIED REACHES IN THE WESTERN BYPASS HIGHLIGHTED

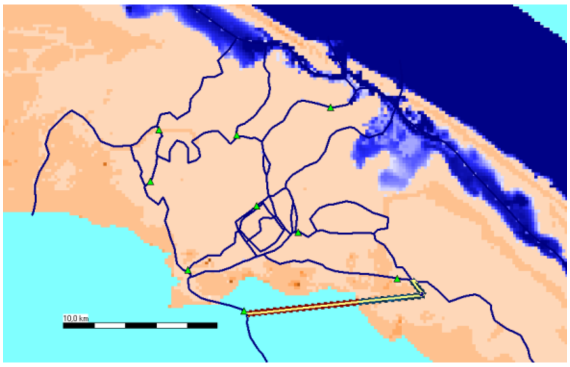


FIGURE 76: SOBEK NETWORK WITH THE EASTERN BYPASS AND CONTOLSTRUCTURES

RESULTS

Initially, the results from the SOBEK model are promising. The first signs of flooding occur in the areas where it is intended to, and the densely populated areas remain dry. The capacity of the western bypass showed later to be insufficient as water flows into the area west of Hue City, see Figure 77 and Figure 78. From the East, water directed through the eastern bypass floods the area northwest of the intended inundation area very quickly. This shows that care should be taken in designing control structures and protection against water from that direction. The model does however show that a large volume of water is stored on the land in the East.

EFFECTIVENESS IN REDUCING FLOODING IN POPULATED AREAS

The double bypass system does not seem capable of directing large enough volumes towards the inundation areas. The changes made in the SOBEK model are big enough to say that increasing those more would be unrealistic. This indicates that more areas need to be flooded to protect populated areas from flooding. This makes the double bypass probably not the most optimal solution.

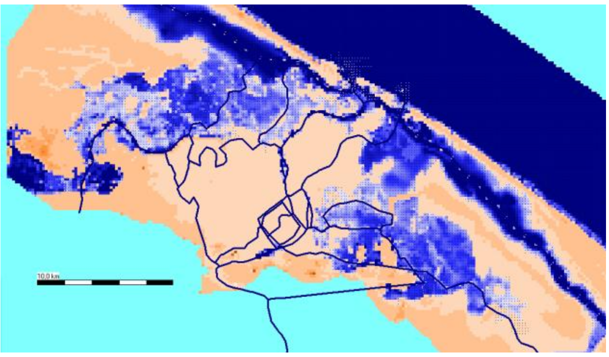


FIGURE 77: FLOODING AFTER 33 HOURS IN A ONCE IN 5 YEAR FLOODING EVENT AFTER CONSTRUCTION OF THE DOUBLE BYPASS

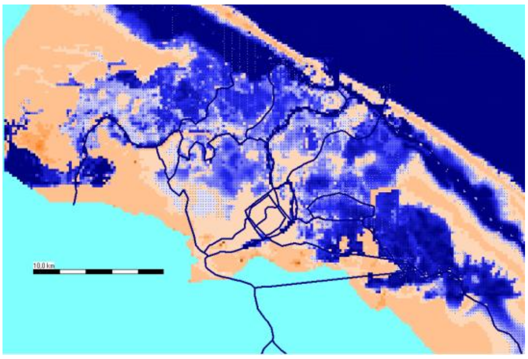


FIGURE 78: FLOODING DURING A ONCE IN 5 YEAR FLOODING EVENT AFTER CONSTRUCTION OF THE DOUBLE BYPASS

SCENARIO 2: LAKE HUE WITH THE EASTERN BYPASS

LAKE HUE

Lake Hue is modelled as a flooded area at the edge of the modelled area. The volume of the lake is schematized by a cross-section with a large width and depth. This makes determining the required storage volume easier than using the 2D flow module. The barrier is modelled by a weir. The eastern bypass has the same characteristics as described earlier. Notable areas that require extra protection against the increased flood levels are the western boundary of the inundation area downstream of the bypass and the airport that borders on the south side of the inundation area.

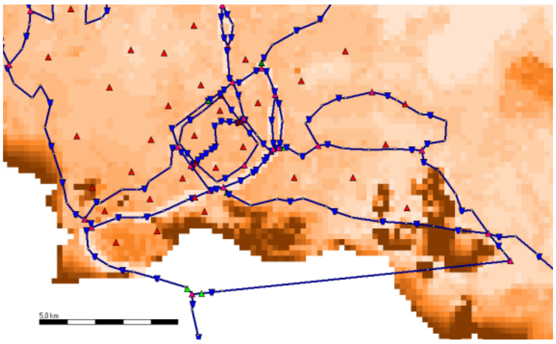


FIGURE 79: LAKE HUE AND EASTERN BYPASS MODELLED IN SOBEK

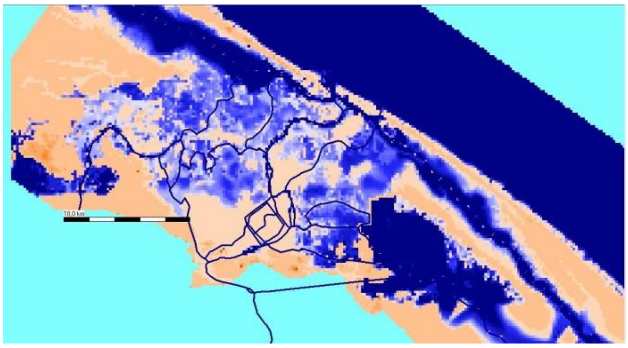


FIGURE 80: FLOODING AFTER A ONCE IN 5 YEAR EVENT IN THE "LAKE HUE" SCENARIO

RESULTS

The flooding that occurs as a result of a once in 5 years event paired with the measures suggested in the “Lake Hue” scenario are shown in Figure 80. The inundation area east of Hue City can clearly be distinguished by the deep blue color signifying a large water depth. The area around Hue city on the other hand remains dry for the largest part. Some flooding still occurs in the lower situated areas due to water from the Bo River, but this coincides largely with lower populated areas. The water depths of flooded areas, except for the inundation area, are all significantly reduced compared with the original situation.

EFFECTIVENESS IN REDUCING FLOODING IN POPULATED AREAS

The “Lake Hue” scenario seems quite effective in reducing the flooding in and around Hue City. The water level ensured by creating a reservoir makes discharging water towards the eastern inundation area easier. The flooding that still occurs in the western part of the project area is flooded by the Bo River. This scenario has not tackled that problem, instead focusing on the problem caused by the discharge from the Huong River. The flooding from the Bo River can still be reduced by taking on that problem specifically, as no changes have been made there so far. This can be done with less effort than in the double bypass scenario as no additional water is diverted in that direction.

COMPARISON OF THE DOUBLE BYPASS AND LAKE HUE SCENARIOS

Both the double bypass as the Lake Hue scenarios does not offer yet the needed protection on their own. The double bypass scenario succeeds at first in diverting the excess water to the west, around Hue City. Nevertheless, the sum of the diverted water and the discharge from the Bo River causes high enough water levels in the streams in the area that flooding occurs. The changes that have been made to the network to get it to this point are so large that further changes to that region are not realistic and a solution should be found elsewhere.

The Lake Hue scenario shows flooding in the same areas as the double bypass scenario does, but the flooding is caused by the Bo River alone. The lack of additional protection allows the flooding to be comparable to the one caused by the diversion of water from the Huong River. This means that there are enough options to counteract the flooding by the Bo River. This makes the Lake Hue scenario more promising than the double bypass scenario.

DISCUSSION ON THE RESULTS OBTAINED WITH THE SOBEK MODEL

The results described above allow us to compare different scenarios, but are not a complete representation of reality. The first large assumption made in the model are the boundaries, the flow from the Bo River, Huu Trach and La Trach were supplied with the model and resulted in a water level in the Huong River that corresponded with the water level during a once in five year event. In reality, this discharge corresponds with the flooding of 1999, which is a once in a hundred year event. Other processes are responsible for reducing the magnitude of the flood. Some possible reasons are the sea water level, the use of rain by the model, or some reason that is not readily discernible. Using the models results to compare the consequences of different alterations in the network should still give a descent image of the reality. Absolute values are however not to be used without careful consideration of their meaning.

The end result of the model is an image that depicts the working of the system. The extent of the flooding under different scenarios show which way water is discharged and how it propagates over land. One can also see area where water accumulates and areas that stay dry. A rough indication of where additional protection is required and what constructions can possibly provide a solution can be used as a starting point for further, more detailed research.

3.2 PRELIMINARY DESIGN: LAKE HUE

From the model, it follows that Lake Hue is the most promising scenario. That is why in this chapter more attention is paid for the design. It will form a preliminary design due to the lack of available data.

3.2.1 STRUCTURAL ASPECTS

The construction of the water retention scenario is worked out in more detail. In this scenario, the peaks of a flood can be shaved off by means of temporary water retention. As calculated in section 3.1.2, the volume of the retention area should be 250 million m^3 (if no safety factors are applied), which leads to a water height of 19 meters above mean sea level.

In this chapter, the structures which are needed to control the discharge and volume of the reservoir are worked out in more detail.

An overview of the functions of the river and the retention area is given in the first paragraph. These functions have led to the functional requirements of the retention area. A list of the needed control structures and components has been formed based on these requirements. A few options have been investigated for each of the components. From these options, the most promising combinations have been derived. From those promising combination, one is rejected after the SOBEK results. This now leaves one promising combination. This combination is called Lake Hue and will be worked out into a preliminary design in this chapter.

FUNCTIONS OF THE WATER RETENTION AREA

The most important function is the possibility to store the water during potential floods. The maximum water level in the reservoir which is needed to cope with the design flood is equal to

19 meters. The height of the dam itself should be larger due to a required freeboard, settlements and additional safety. The natural bottom contours are used as much as possible to store the water in order to avoid expensive construction works. In the north, at the connection with the Huong River, a dam needs to be constructed since the surrounding area is not elevated.

After the flood period, the water should be released to empty the retention area again. This calls for the use of movable gates which are closed during flood conditions while they can also be opened to release the water again. The capacity of the downstream river is approximately 600m^3/s before the City of Hue gets flooded (from the SOBEK model), to add some safety, the maximum outflow of the gates is limited to 500 m^3/s.

At the moment, the part of the river upstream of the newly built dam is only used by small boats for transport of raw materials. In order to preserve the function of navigation for the river, a lot of adjustments to the dam are needed, while 30 kilometers further upstream another dam is located in the Ta Trach and the Huu Trach River. These reservoirs already form a barrier for vessels. These adjustments are not likely to pay off in the end. It is decided that the dam will form a barrier for navigation.

Furthermore some safety measures should be provided to prevent overflow of the entire dam. This can be done in the form of a spillway, which is used when the water level approaches the edge of the reservoir. By doing so, the overflow can be steered to less vulnerable areas. This spillway should start to work when the maximum design water level is reached. Because water has to flow over the spillway an additional head is needed. This makes the dam 2 meters higher, resulting in a total dam height of 21 meter.

FUNCTIONAL REQUIREMENTS

The study of the different functions of the water retention area has led to the following functional requirements:

- The maximum retention level should be at least 19 meters
- The freeboard should be at least 0,5 meters, settlements excluded
- The maximum regular outflow of the dam may not exceed 500 m^3/s
- The spillway should start discharging when the water level exceeds 19 meters
- The stability of the structure should be guaranteed up until a head difference of at least 21 meters
- The structure should be designed for a lifetime of at least 100 years

A remark has to be made that the climate change is not taken into account in the design.

DESIGN OF THE DIFFERENT COMPONENTS

An overview of the whole retention area is given in Figure 81.

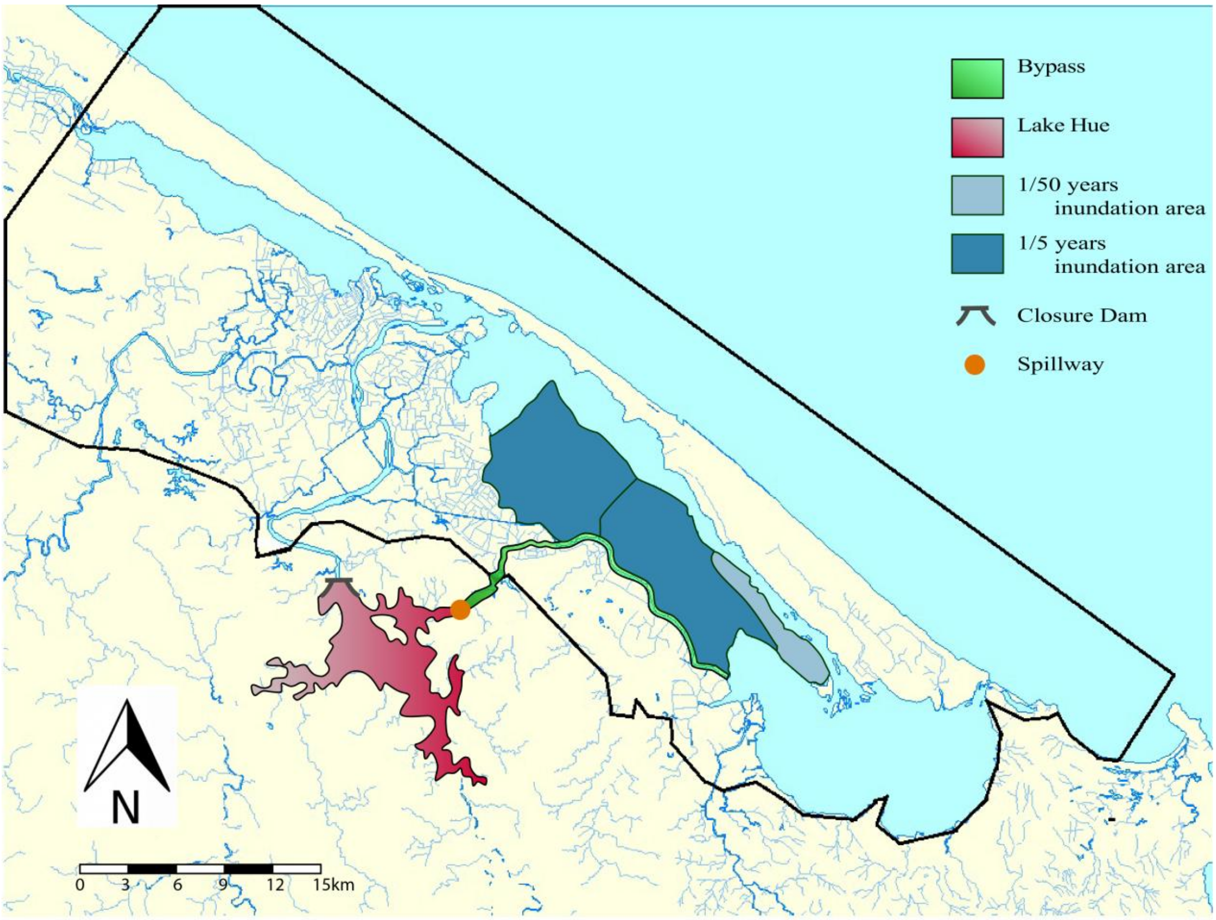


FIGURE 81: OVERVIEW OF THE RETENTION AREA

In the following chapter, the different options for each component will be worked out in more detail. The components which are investigated are the dam, the outlet(s) and the emergency spillway.

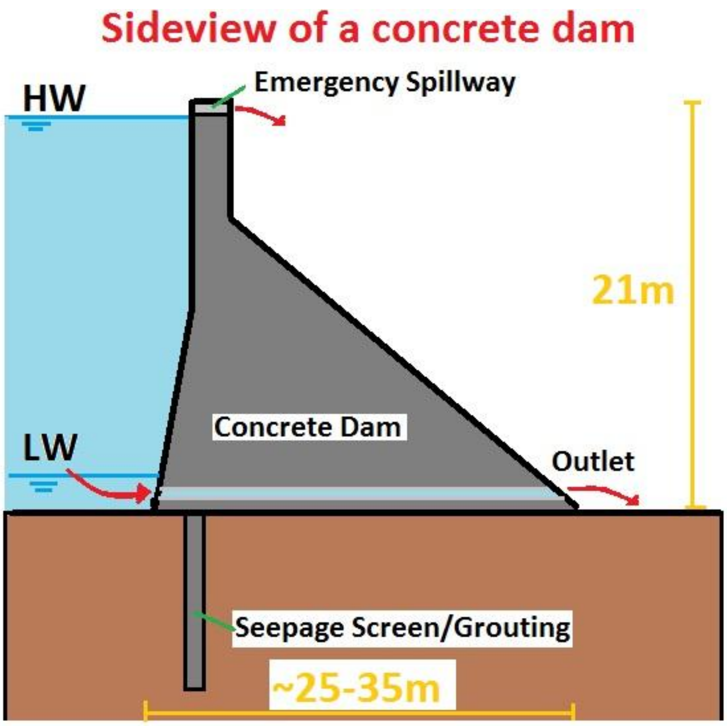


FIGURE 82: SCHEMATIZED SIDE VIEW OF CONCRETE DAM

DAM DESIGN

In the northern part of the area, a dam needs to be constructed to retain the water during the flood periods. The water should be retained up to a height of 21 meters. 19 meters is reserved for the design water level, while a freeboard of 200 centimeters is needed. This freeboard is especially for creating a water head for the emergency spillway. A length of the dam of approximately 800 meters is needed to elevate the whole surroundings up to a height of 21 meters.

The dam can be constructed in two different ways: one option is to make use of concrete as construction material while the other option is to create an earthfill dam with an impermeable core. For both the options, stability is provided by the weight of the dam itself. Both options are discussed below.

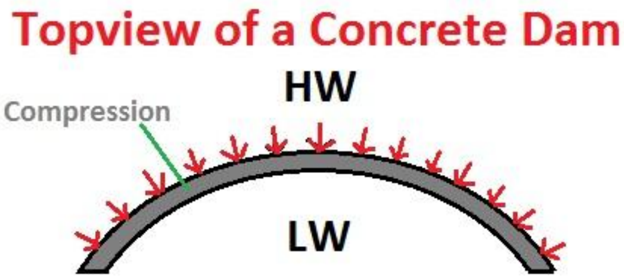


FIGURE 83: TOPVIEW OF A CONCRETE DAM

OPTION 1: CONCRETE DAM

The concrete dam gains its stability by its own weight. A large amount of concrete has to counterbalance the maximum of 21 meters water pressure. The required width of the base of the dam will be in the order of 30 meters. The dam will be curved towards the high water side to ensure that the whole structure is in compression, which is most favorable for the concrete. A sketch can be seen in Figure 82, an overview from tensions in the dam can be seen in Figure 83.

The main advantage of a concrete dam is that the width of the dam is limited compared to an earthfill dam. Besides, the quality of the structure can be controlled in a better way since the variability in the quality of concrete is less than the one of soil. The disadvantage of this option is that a lot of concrete and reinforcement is needed, which is more expensive than ground. An artist impression of a concrete dam into the environment is given in Figure 84.

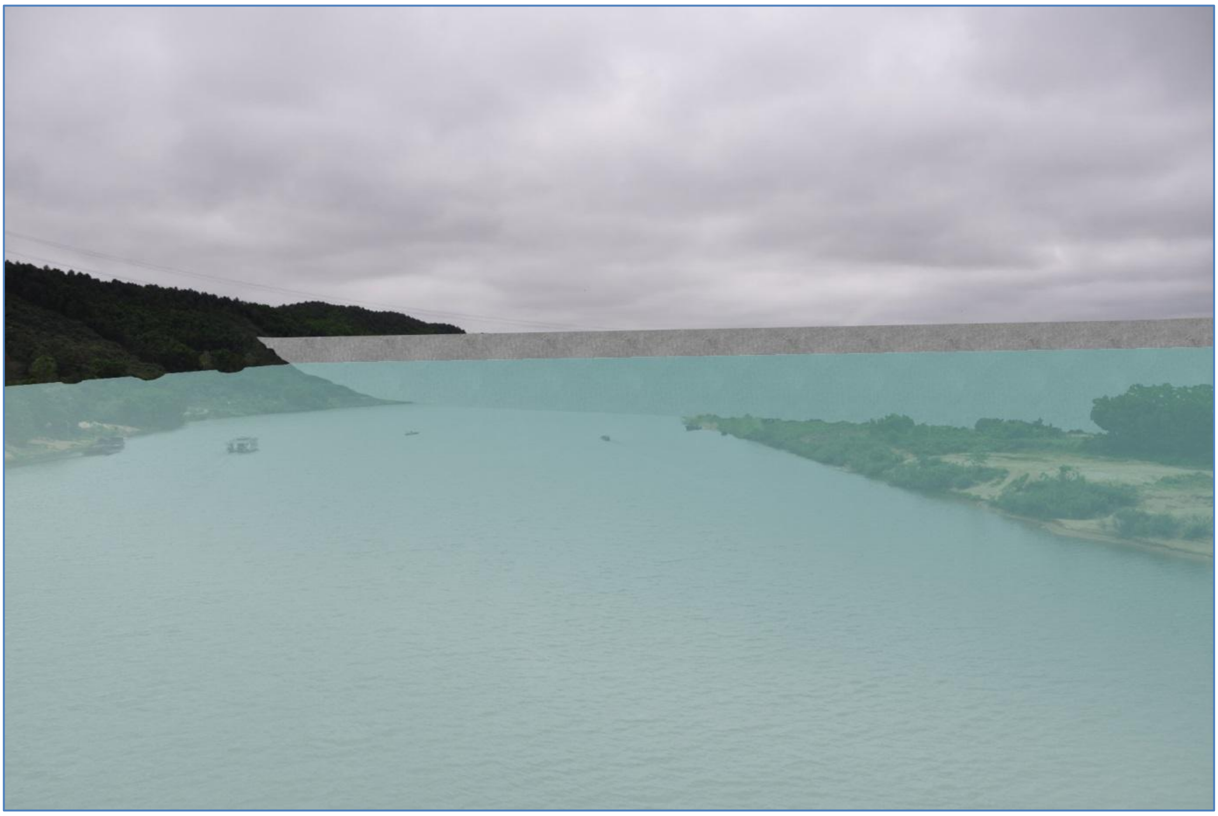


FIGURE 84: ARTIST IMPRESSION OF THE CONCRETE DAM

OPTION 2: EARTHFILL DAM

For the earthfill dam two issues are important: the micro-stability of the grains and the macro-stability of the whole structure. The width of the base of the structure will be approximately 150 meters. The core of the dam consists of an impermeable material such as clay, which has to reach until the impermeable ground layer. In this way seepage and washout of materials through

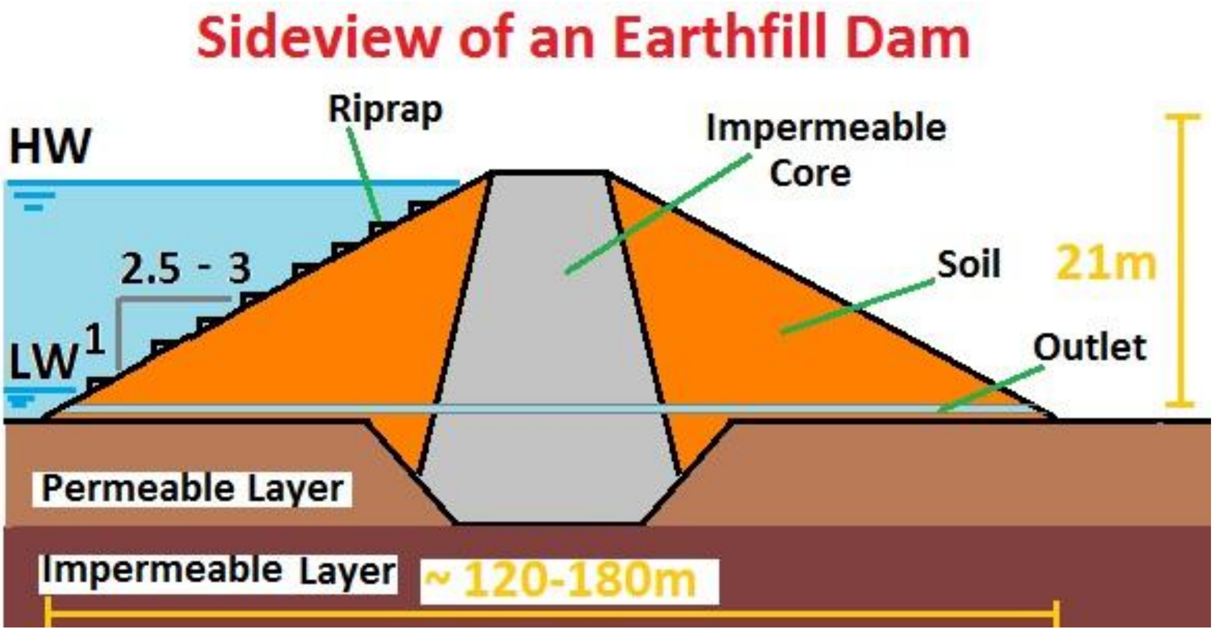


FIGURE 85: SCHEMATIZATION OF THE SIDE VIEW OF AN EARTHFILL DAM

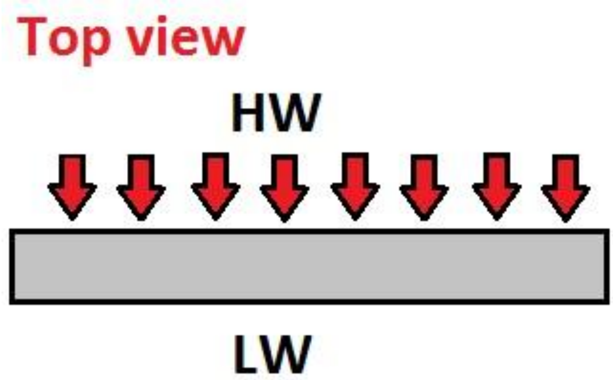


FIGURE 86: EARTHFILL DAM TOPVIEW

the dam can be prevented. Opposite to the curved earthfill dam, this dam will be straight between the banks on both sides. A sideview is visible in Figure 85.
The main advantage of this option is that mostly natural materials are used. This option is more pleasing to the eye than constructing in concrete.

The disadvantage is the large volume of ground which is needed. The structures which are required for the regulation of the discharge are also harder to construct since the length which the water has to travel through the dam has increased.
The final decision on the type of dam should be based on the availability of materials, space, labour and time. An artist impression of the earthfill dam is given in Figure 87.

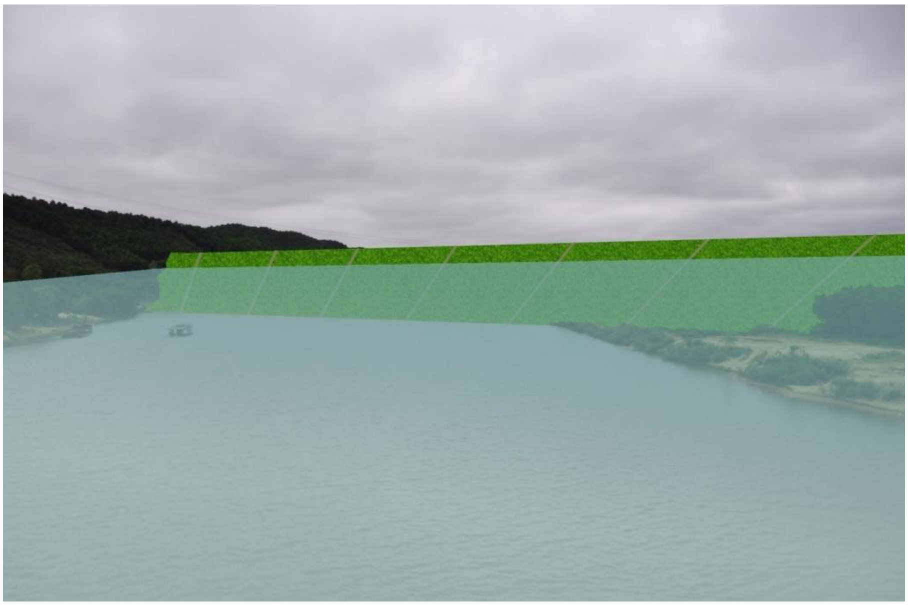


FIGURE 87: ARTIST IMPRESSION OF THE EARTHFILL DAM IN ITS SURROUNDINGS

DESIGN OF IN- AND OUTLET

Depending on the dimensions and material of the dam multiple types of outlets are possible. In this paragraph an overview of the possibilities are given.

OPTION 1: TUBES WITH VALVES ON BOTTOM LINE

When an earthfill dam is constructed, an option to control the outflow of the reservoir through the dam is the installation of tubes through the dam which can be closed by valves. Multiple tubes can be installed over the total width of the dam.

The tubes are installed just above the bottom level. In this way water can pass the dam all year, even at low discharges. When the tube is installed a bit above the bottom level there is some space left for sedimentation in the future.

When flooding is expected, the valves will take care of the regulation of the outflow. After the rainy period water can be released through the tubes. By setting the valves at the right level, there is a controlled outflow of water through the dam which ends up in the Huong River.

The water which is transported through the tubes will flow into a stilling basin made of concrete. The turbulence created in this basin will dissipate the energy of the flow, so that the water can flow out calmly and erosion downstream is prevented.

The advantage of this option is that all water can leave the reservoir by mean of all tubes throughout the whole year. The disadvantage is that when the pressures and flow velocities at the inflow and outflow of the tubes are very high, the risk of erosion is substantially. So a lot of erosion measures must be taken. A schematization is given in Figure 88.

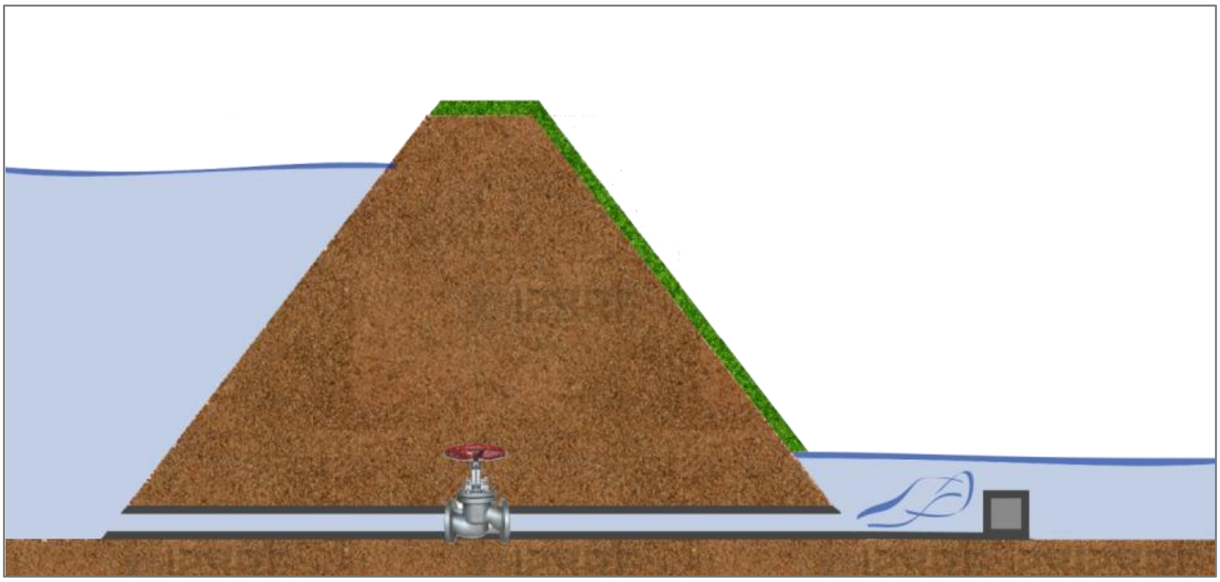


FIGURE 88: TUBES WITH VALVES AT BOTTOM LEVEL

OPTION 2: TUBES ON DIFFERENT HEIGHTS

The previous solution can also be adapted in the sense that the tubes are located on different heights. When all tubes are on bottom level the pressure in the tubes is very high and the water has a big velocity while leaving the tubes. When some tubes are placed on a larger height, the pressure and flow velocities near the bottom will decrease. The energy of the water will be dissipated by means of a chute. In this solution, some tubes have to be on ground level as well, in order to be able to flush the reservoir after the rainy season. Downstream of the dam some bed and cover protection is necessary to prevent erosion.

The advantage of this solution is that water can be divided over multiple valves and that the risk of erosion at the downstream of the dam is less.
The disadvantage of this option is that in the case when there is a low water level all water has to leave through the lowest tubes, so this option requires more tubes than the first option. A schematization is given in Figure 89.

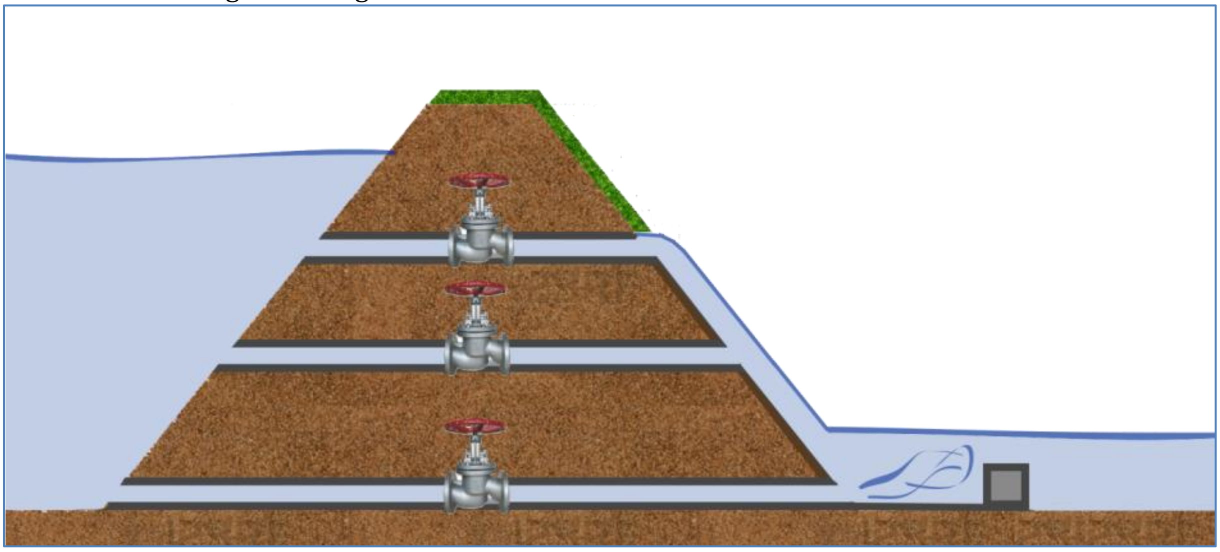


FIGURE 89: TUBES WITH VALVES ON MULTIPLE HEIGHTS

OPTION 3: GATE AND CULVERT

The third option is to design of a gate in front of a culvert. This option has got a lot of similarities with the first option with the difference that in the first option there are a lot of tubes intersecting the dam. In this option just a single or couple of culverts must be present.

Advantage of this option is that maintenance is cheaper and easier because there are less valves/gates to maintain. The disadvantage is that the valve can be damage easier compared with the first option due to its location. In Figure 90 and Figure 91 a schematization of respectively the side view and front view is given.

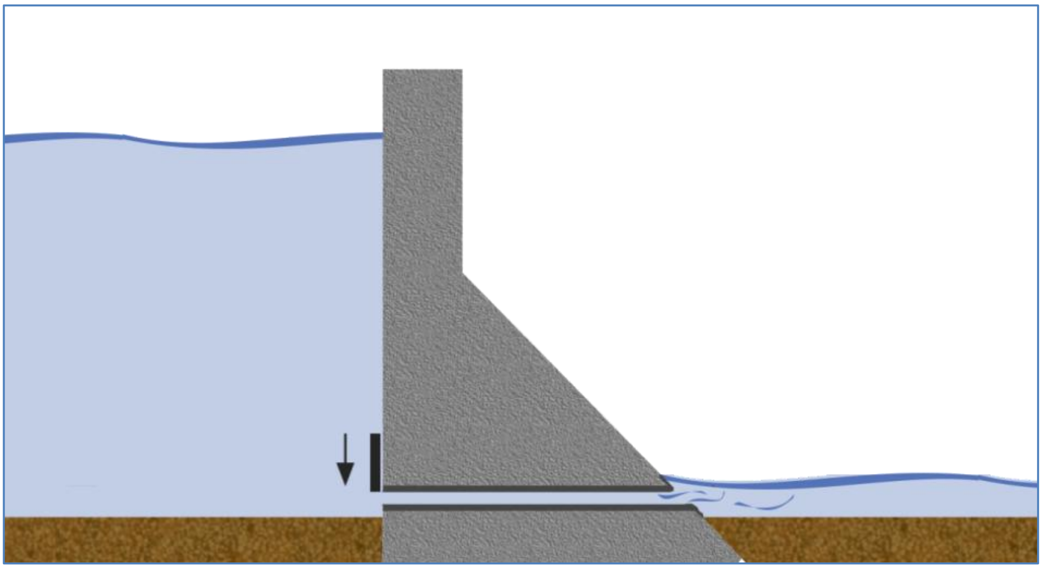


FIGURE 90: SIDEVIEW OF A DAM WITH A GATE IN FRONT OF THE CULVERT

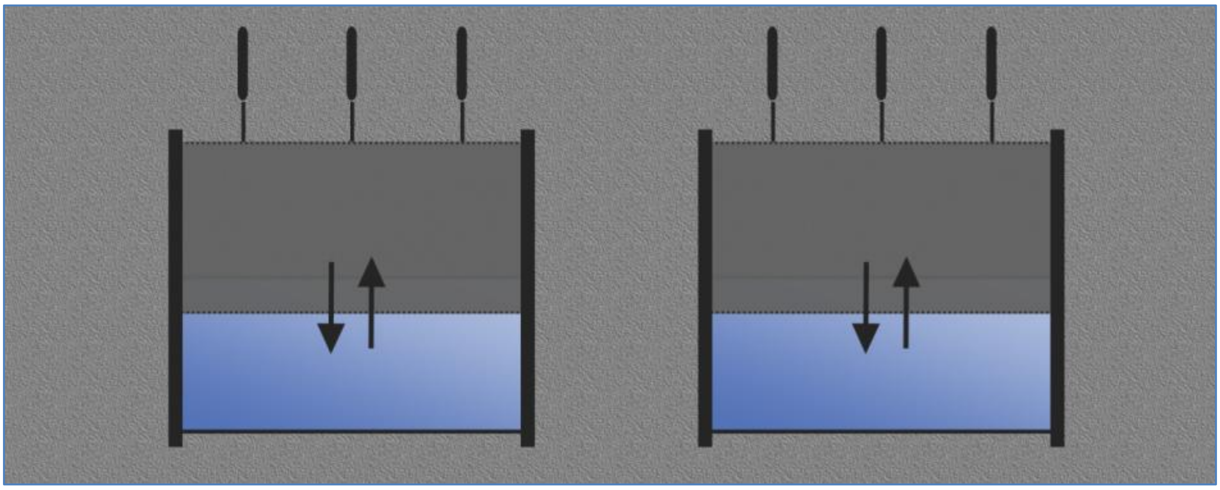


FIGURE 91: GATES INSTALLED IN FRONT OF THE CULVERT

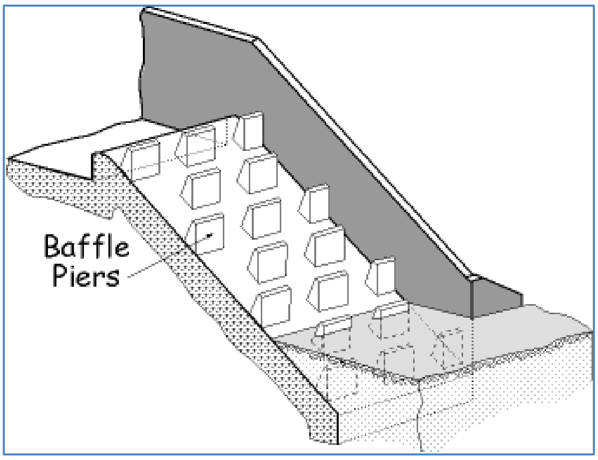


FIGURE 93: CONCRETE SHUTE WITH BAFFLE PIERS FOR ENERGY DISSIPATION (WWW.DNR.STATE.OH.US)

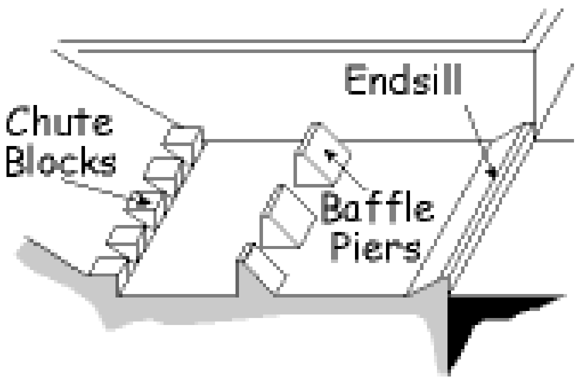


FIGURE 92: A STILLING BASIN FOR ENERGY DISSIPATION (WWW. STRUKTS.COM)

ENERGY DISSIPATION

Water will flow with a large velocity through the dam. Without any measures, these large quantities of water will cause a lot of damage because of erosion. To prevent this damaged caused by fast flowing water some measures have to be taken. One of the possibilities is the use of a chute on the slope of an earthfill dam or at the outlet of a concrete dam. Turbulent water will hit different elements and lose its energy. See also Figure 92.

Another possibility to prevent damage caused by fast flowing water is the use of a stilling basin. A basin made out of concrete where turbulent water can't cause any damage. Bounded by a small raise of the bottom water can flow out smoothly out of the basin. A stilling basin is shown in Figure 93.

EMERGENCY SPILLWAY DESIGN

In order to prevent overflow of the entire basin, an emergency spillway needs to be constructed which releases the water if a certain water level is reached. This spillway helps to discharge the water in a faster way when dangerous water levels occur than just via the regular outlets.

Two different options are considered: the morning glory spillway and the ungated spillway.

OPTION 1: MORNING GLORY SPILLWAY

The morning glory spillway is no more than a vertical, hollow tower with an opening on the top. The height of the tower is determined by the water level for which the dam is designed. The size of the opening should be large enough to keep the water level in the retention area more or less constant, or with other words: the inflow should be in balance with the outflow.

The advantage of the morning glory spillway is the shape: the circular shape of the opening at the top leads to a large perimeter compared to the surface area. The perimeter is a measurement for the total inflow: this means that a relatively small structure is needed to have a large discharge.

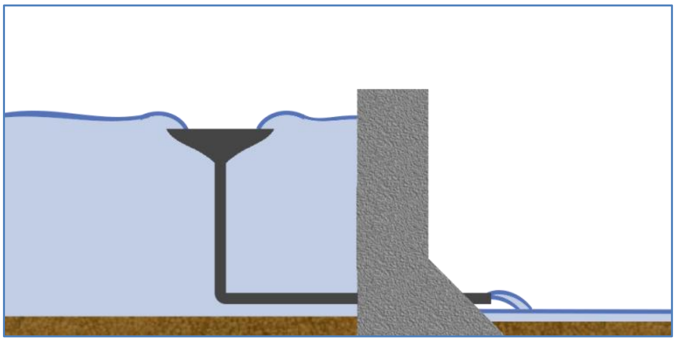


FIGURE 94: PRINCIPLE OF A MORNING GLORY SPILLWAY

The disadvantage is the extra excavation works which are needed to install the pipeline through the hilly surroundings. A sketch is given in Figure 94.

OPTION 2: UNGATED SPILLWAY

In this option, a certain part of the area around the lake is constructed a little bit lower than the rest. When the water level reaches dangerous heights, this part will be over flown at first. This spillway will be located at the East of Lake Hue. In this way, the surplus of water can be guided directly to the lagoon. The stream to the lagoon should be properly protected against erosion and bounded by dikes to prevent flooding of vulnerable parts of the province.

The advantage of this option is the simple construction of the spillway itself. The disadvantage of this option is the additional measures which have to be taken such as the construction of dikes, a chute, and bottom protection near the spillway. A sketch is given in Figure 95

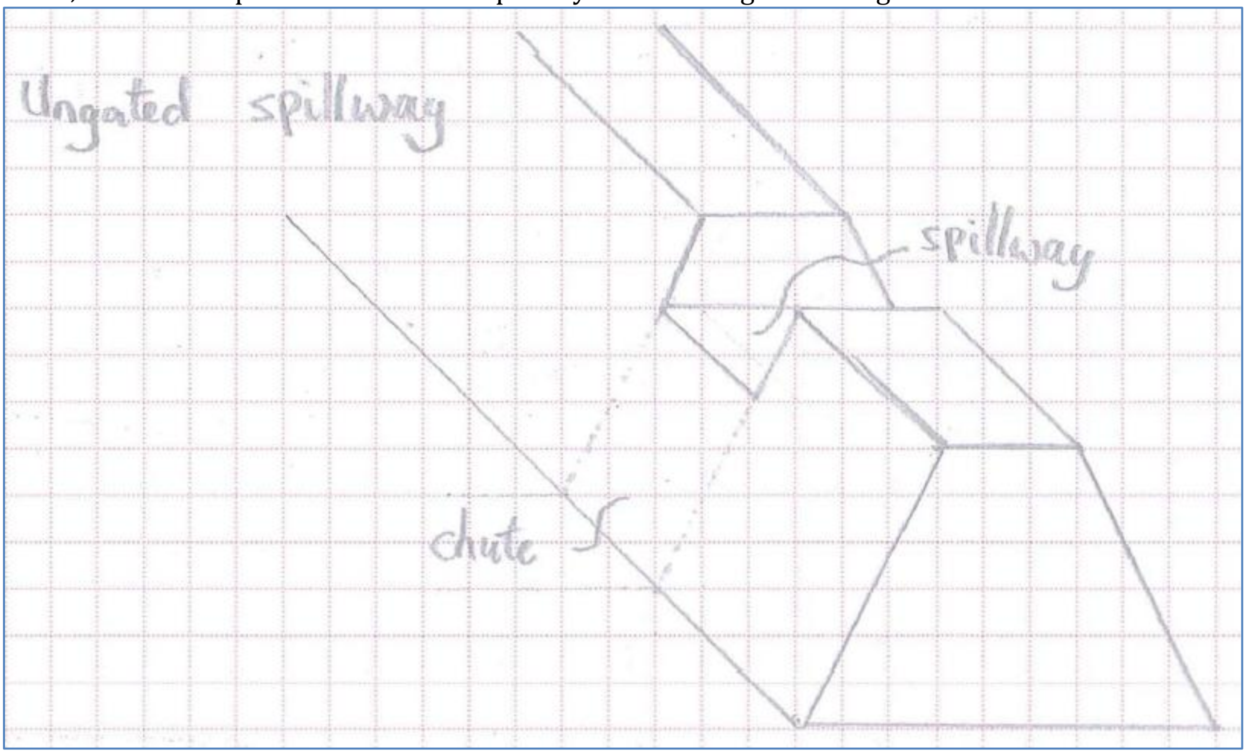


FIGURE 95: PRINCIPLE OF AN UNGATED EMERGENCY SPILLWAY

COMBINATIONS

In order to come to the global design, different combinations of the above mentioned options are considered as can be seen in Table 12.

TABLE 12: POSSIBLE OPTIONS FOR DAM AND RESERVOIR DESIGN

Component	Option 1	Option 2	Option 3
Type of dam	Earthfill	Concrete	
Type of inlet	Tubes on bottom	Tubes on different heights	Gates for culverts
Type of energy dissipation	Chute	Stilling basin	
Type of emergency spillway	Morning glory	Ungated spillway	

From this set of options 3 combinations are made, these are described in the paragraphs below.

COMBINATION 1

This option consists of an earthfill dam combined with tubes for discharging the water from the bottom line. To prevent damage at the downstream part of the dam in this combination a stilling basin is chosen. For this option an ungated spillway that becomes active in emergency situations is used.

COMBINATION 2

The second option will consist of a dam made out of concrete. Gates in front of the culverts ensure the water output. For this option a stilling basin at the end is installed in order to regulate the outflow of turbulent water. A morning glory emergency spillway is installed near the corners of the dam to ensure the safety.

COMBINATION 3

The dam of the third combination is made out of earth, outlet tubes are constructed at different heights in the dam. A chute is made on the outside of the dam. The dam will in this option be constructed with an ungated spillway in the middle of the dam.

SELECTION

All combinations mentioned above have their benefits and disadvantages. A small multi-criteria-analysis (MCA) is made to come to the best solution. Each combination will be elaborated on 5 different criteria, and be rated with a mark between 1 and 3. The combination with the highest score will be chosen. The MCA is visible in Table 13.

TABLE 13: MCA ON THE DIFFERENT COMBINATIONS

Criteria	Relative weight	Combination 1	Combination 2	Combination 3
Costs	3	3	1	2
Integration into environment	1	3	1	3
Maintenance	2	2	2	3
Availability of materials	2	3	2	3
Technical feasibility	2	3	2	1
TOTAL		**28**	**16**	**23**

From the above it is clear that combination 1 is the most favourable option. This combination has the lowest construction costs in comparison with the other options. Soil is a common and widely available construction material. For design and calculations combinations 1 will be elaborated further.

3.2.2 STRUCTURAL DIMENSIONS

In this section some structural dimensions will be determined, like the needed volume of soil needed for the earthfill dam and the amount of tubes needed for the outlet and the dimensions of the emergency spillway.

VOLUME OF SOIL NEEDED

To calculate the quantity of soil required for building the dam all dimensions have to be known. In this paragraph the assumption is made that the whole dam consists of clay with an internal angle of 20 degree. A safety factor of 10% will be used and there will be calculated with an internal friction angle of 18 degree. First calculate the width of the river in the middle of the dam. Dimensions are given in Figure 96.

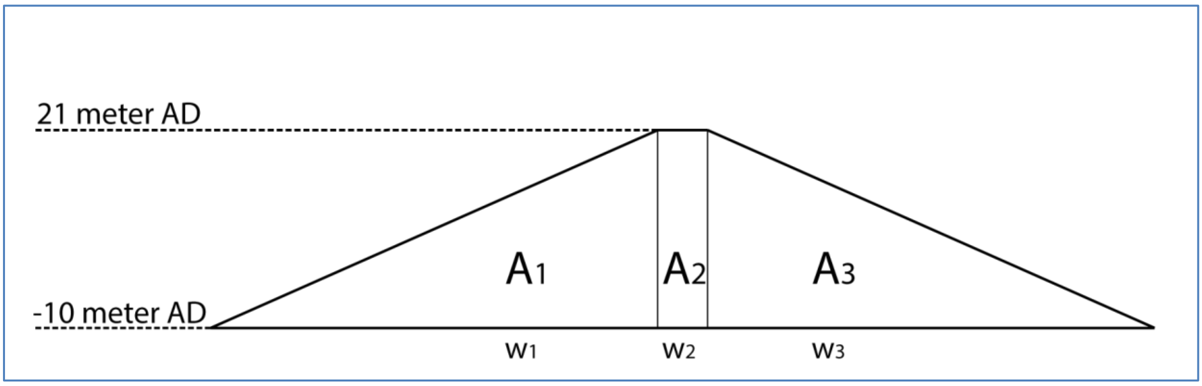


FIGURE 96: DIMENSIONS OF THE DAM AT THE MIDDLE

The top of the dam is lying at a level of 21 meter above datum. The lowest point is located in the middle of the river and has a height of 10 meter below datum. The total height of the dam measured from top to bottom is thereby 31 meters. This is also the place where the outlet tubes are installed and therefore the width of the dam must be known at this place.

$$w_1 = w_3 = \frac{h}{\tan 18°} = \frac{31}{\tan 18°} = 95.4\ m$$

$$w_2 = 8\ m$$

In the middle of the dam at the point where tubes are installed to let the water flow through the dam has got a total width of:

$$W = w_1 + w_2 + w_3 = 95.4 + 8 + 95.4 = 198.8\ m$$

Than the volume of the dam is calculated using Matlab software. This Matlab file is shown in appendix F. Height of the dam is set at 21 meter above reference level. According to the Matlab calculations the total volume of soil required for the earthfill dam is $V = 893.000 m^3$

DIMENSIONS OF TUBES

In order to let the water flow through the dam, tubes are installed at the bottom level of the dam. Multiple tubes have to be installed because of the large quantities of water that have to pass the dam. In this scenario the assumption is made that when there is a minimum head difference of 1 meter the system must be able to transport 500m³/s of water through the dam. In the case when the dam is full and there is a head difference of 19 meters some tubes have to be closed to ensure that there is a maximum flow of 500m³/s. From the previous paragraph it is clear that the width on bottom level of the dam is L=198.8 meters. Further it is assumed that the Nikuradse roughness (k_n) of the tube wall is 1mm and the wall of the tube is hydraulic smooth. Tubes with a diameter (D) of 3 meter are chosen to use in the dam. When smaller tubes are used the friction losses will increase and tubes with a larger diameter are difficult to transport by truck. A tube with a diameter of 3 meter is between those extremes.

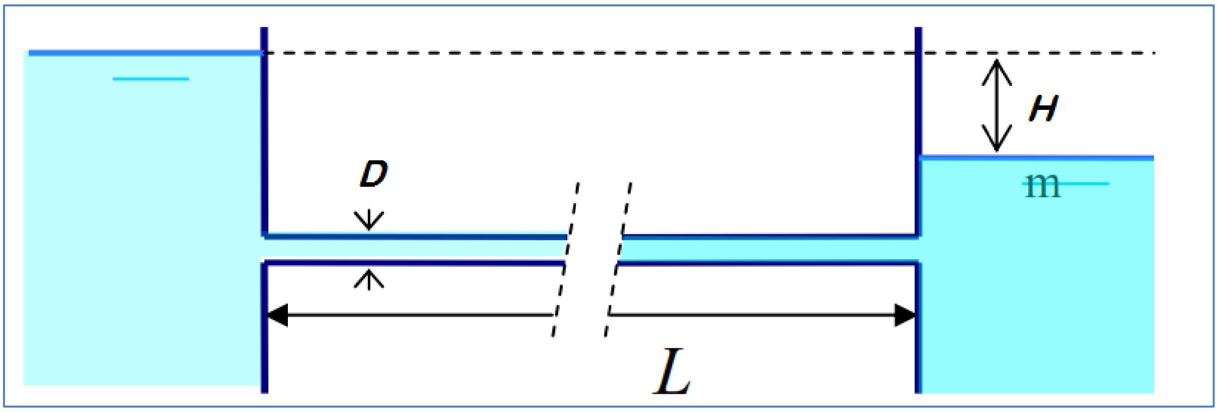


FIGURE 97: SKETCH OF THE DIMENSIONS AT THE TUBES

First the friction coefficient of Darcy-Weisbach will be calculated using the following formula:

$$\frac{1}{\sqrt{f}} = 2 * \log\left(\frac{3.7 * D}{k_n}\right)$$

This formula gives a friction coefficient of $f = 0.0153$. After this calculation the water velocity will be calculated using the energy head loss. Where ΔH has a minimum value of 1 meter,

$$\Delta H = \left(f * \frac{L}{D} + 1\right) * \frac{U^2}{2 * 9.81}$$

From the equation above it is clear that $U = 3.17$ m/s. Now dimensions from the tube as well as the flow velocity are known. With this information the waterflow trough one single tube can be calculated using:

$$Q = \frac{1}{4} * \pi * D^2 * U = 22.07\ m^3/s$$

When 500m/s has to be transported over the dam the number of tubes rounded up to the next integer above is:

$$N_{tubes} = \frac{500}{22.1} = 23\ tubes$$

Now the assumption of hydraulic smooth wall flow has to be checked using the following formula where the thickness of the laminar sub layer is calculated. For the viscosity a value of $\nu = 1.4 * 10^{-6}$ is held.

$$\delta = \frac{11.6 * \nu}{\sqrt{\frac{f}{8}} * U} = 1.17 * 10^{-4}\ m$$

The value of δ is a lot smaller than the Nikuradse roughness which is $k_n = 1mm$. So the thickness of the laminar sub layer is relatively small compared with the roughness of the pipe. So the influence of the laminar sub layer on the water velocity inside the pipe can be neglected. So only the Nikuradse roughness can be used in these first calculations.
In the case of a reservoir that is completely filled the hydraulic head is 19 meter instead of 1 meter. The equations above can be repeated to calculate the flow through a single tube and the number of tubes required. On each single tube $Q = 101.1\ m/s$ and 4.9 → 6 tubes are required so the other 15 tubes can be closed.

SIZE OF SPILLWAY TO THE EASTERN BYPASS

The spillway leading to the eastern bypass will be designed to discharge the excess water from the basin towards areas with a relatively low return period for flooding. The volume that needs to be discharged in a once in 100 year storm situation is 4700m³/s (storm of 1999), this is determined in section 3.1.2.

A sharp crested weir is most suited to discharge this large amount of water as the energy head required is as low as possible. For this situation, an available head of 2 meters is chosen. This energy head is assumed to be equal to the water level in the reservoir, because the velocity head in the reservoir can be neglected. The last assumption made is that free flow conditions apply. This applicability of this assumption is likely as the height of the reservoir is large.
The formula for free flowing water over a weir is shown below.

$$Q = c * B * H^{\frac{3}{2}}$$

Entering the discharge (Q); discharge coefficient (c) of 1.9; and the energy head above the crest (H) gives a required width of just under 900 meters.

3.2.3 COST-BENEFIT ANALYSIS

A cost-benefit analysis is included to check if the proposed solutions are profitable in terms of value on the long term. The estimation of the costs only includes the direct measurable costs and thus gives the lower bound of the total costs.

This chapter starts with a description of the set-up and calibration of the model. Hereafter, the use of the model and the results are shown, followed by a conclusion.

SET-UP OF THE MODEL

First of all a study is performed to check the distribution of the GDP over the different economic sectors. This distribution is used to relate the functions of the land to the damage per unit of surface area. An extensive elaboration of this can be found in Appendix E.

This study has resulted in the damages caused by inundation of the area with a certain landuse. Those values can be seen in Table 14.

TABLE 14: DAMAGES OF THE INUNDATION OF A CERTAIN LANDUSE TYPE

Land use	Costs of a flood (€/inundated hectare)
Urban area	Depends on inundation depth
Agriculture	375,-
Aquaculture	3250,-

The damage to houses in the inner city depends on the inundation depth (Pistrika, Jonkman, 2010). The following relation between the value of a house and the damage caused by a flood is assumed:

TABLE 15: THE VALUE OF DAMAGE FOR THE URBAN AREA WITH DIFFERENT INUNDATION DEPTHS

Inundation depth (meters)	Damage factor α
0-1 m	0,05
1-2 m	0,2
2-3 m	0,4
>3 m	0,5

Furthermore, a distinction has been made between urban houses and rural houses. Urban houses are assumed to be worth €10.000 while the rural houses are assumed to be worth €1500,- (ESCAP, AIT, 2012).

The number of inundated houses is based on both demographic maps and literature about the average size of a household.

After the set-up of the model, the different parameters were calibrated on the flooding of 2007. The available data on the inundated areas, land use and total costs are used to the estimated damages of a flood per type of land use per hectare.

After this, both of the proposed interventions in the system are modelled in SOBEK to investigate the effectiveness of both of the considered improvements of the system. The estimated amount of damage after an intervention has been divided by the damage without the intervention. This ratio has been derived from the SOBEK model of a one in five years flood. The damage reduction caused by the interventions against flooding with a different return period is assumed to be proportional to the total damage of the flooding.

Now that the damage reduction of floods are known, floods with return periods of respectively 1 year, 5 years and 50 years are distributed over a reference period of 50 years. In the reference period, 40 floods with a return period of one year, 9 floods with a return period of 5 years and one flood with a return period of 50 years are included. The ratios of effectiveness of both of the options are multiplied by the damage of a flood in the reference scenario which is derived from literature. The reduction of risk caused by the interventions can be seen as the benefits of the

interventions. The costs can be split up into construction costs and maintenance costs. For a first estimate, the yearly maintenance costs are assumed to be 1% of the construction costs. The construction costs of the water retention area and the bypasses have been based on reference projects.
The future costs are translated to the net present value by means of a discount rate. This discount rate is defined as the growth of the GDP minus the inflation in the area. A value of 2% is considered to be correct (Cong, 2013).

USE OF THE FLOOD MAPS

The difference in damage for different floods, construction costs and maintenance costs are depicted in Table 16. All of the costs are in millions of Euros.

TABLE 16: THE DIFFERENCE IN DAMAGE FOR DIFFERENT FLOODS, CONSTRUCTION COSTS AND MAINTENANCE COSTS

Scenario	Costs of a flood with return period of 1 year	Costs of a flood with return period of 5 years	Costs of a flood with return period of 50 years	Construction costs (€*10^6)	Maintenance costs (€*10^6)
Reference	12,9	41,0	71,8	0	0
Bypasses	5,9	18,5	32,5	300	3
Retention Area	2,7	8,5	14,9	150	1,5

RESULTS OF THE MODEL

The data is processed with help of Microsoft Excel. Figure 98 shows the cumulative costs of the different scenarios in time.

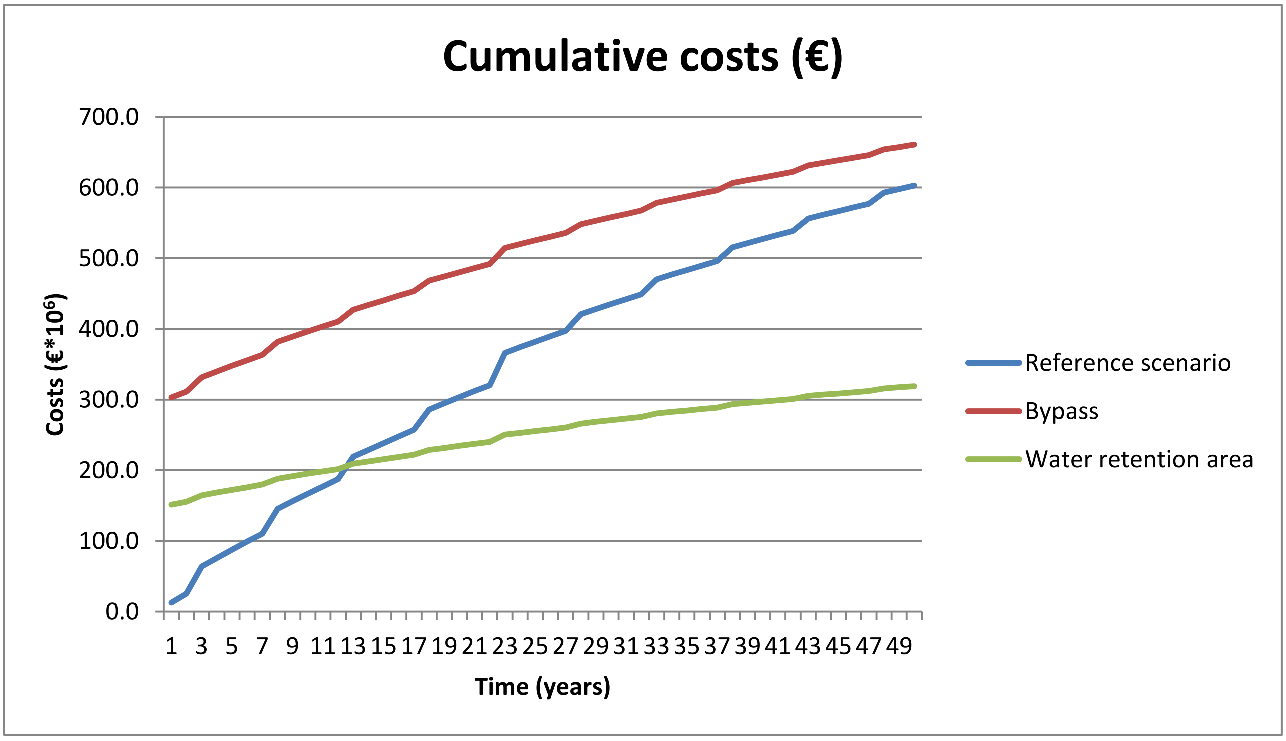


FIGURE 98: THE CUMULATIVE COSTS OF THE DIFFERENT SCENARIOS AGAINST TIME

INTERPRETATIONS

The costs in the first year are mostly the result of the construction costs, which is of course the lowest for the reference scenario. The steepness of the graph is caused by both the damage of floods and construction costs. The steepness is the lowest for the water retention area, since the effectiveness of this solution is the largest. The slopes tend to be milder as the time passes since future costs are reduced by the discount rate of 2%. The lines of the graphs are not smooth because the damage of floods is not equal every year. The steps in the graphs are caused by one in five- or one in fifty year floods.

The water retention area appears to be the most beneficial solution. It is still profitable up to construction costs of about 350 million Euros after the reference period of 50 years.

Although the results seem very promising, still a lot of research has to be done to improve the model of the costs in order to reduce the uncertainties. Many assumptions have been made which still have to be checked for their applicability.

3.3 CONSEQUENCES OF THE TWO SCENARIOS ON SOME HYDROLOGICAL FUNCTIONS

In this section the consequences of the two scenarios are discussed. The water quality, water resources during the dry season, rural drainage, the drainage in the City of Hue, and the river morphology will be discussed.

3.3.1 WATER QUALITY

During the dry season, a low discharge from the rivers in the Thua Thien Hue province can lead to an increased intrusion length of saline water. Several measures have already been implemented to reduce the intrusion length. Some streams are closed with small dams or gates to limit water from the sea to flow through. Other measures are the construction of reservoirs in the mountainous region of the province. The Huong Dien and Binh Dien reservoirs are primarily built for hydro-electric power production, but do create a stable discharge during the dry season, leveling the flow. The Ta Trach reservoir, with flood control as its primary function also plays a big role in the reduction of saline water intrusion.

FIGURE 99: AN EXAMPLE OF A CLOSED OFF STREAM TO PREVENT SALT INTRUSION

FIGURE 100: AN EXAMPLE OF A CONTROL STRUCTURE THAT LIMITS SALINE WATER FLOW INTO THE BASIN

The scenarios discussed in this project have a small impact on salt intrusion. The double bypass could create a negative impact if flow through the Huong River is restricted to much, creating a very low discharge. Had this scenario proven promising, than the design of the control structure should have taken the minimal discharge into account. The Lake Hue scenario would most likely not have an impact on the salt intrusion as it would not be functioning in the dry season. Also, the two reservoirs upstream from the lake would level the discharge passing the lake without interruption. The western bypass connected with the lake will not take a part of the discharge during the dry season.

Reservoirs in the area have already shown to have an impact on another aspect of the water quality. The reservoirs in the area have already caused an increase in iron and manganese content in the water (MASC 2013). This increases the cost of water treatment for domestic use. The increased iron and manganese content is caused by a lower oxygen concentration in the water. Aeration system can provide a system, but increase the investment cost. The construction of Lake Hue might have a similar impact, but this depends on the time that the lake is inundated.

3.3.2 WATER RESOURCES DURING THE DRY SEASON

The two scenarios that have been discussed do not have a negative effect on the supply of water in the dry season. The flow of water is not changed during the dry season, leaving the situation unchanged. The Ta Trach reservoir that is under construction will increase the available water in the dry season. This amount of additional water is already sufficient for replenishing the lack of water during the dry season.

3.3.3 RURAL DRAINAGE

Draining an inundated area faster after a flooding event means the land can be used earlier than it would otherwise. Especially the areas that are used to store the water that would cause more damage elsewhere contain a large volume of water that needs to flow out. The drainage is limited by the ground level next to water ways. Dikes and other defense measures create an obstacle that creates difficulties for drainage. Options to remediate this are for example gates in the dikes, culverts with gates or pumps. The existing irrigation facilities could also be adapted to work both ways, when the water level is high enough on land and low enough in the canal.

FIGURE 101: EXAMPLE OF A GATE IN A DIKE

FIGURE 102: IRRIGATION CANAL THAT COULD BE USED TO DRAIN AN INUNDATED AREA

Both scenarios use inundated land for water storage, and good drainage is part of a well-designed storage area. Lake Hue can be drained relatively easily because of the natural gradient in the land. The inundation area downstream from the spillway does not have this characteristic and will possibly need improved drainage facilities. The same goes for the inundation areas in the double bypass scenario. This scenario has the added difficulty that a lot of raised dikes are part of the solution, limiting the natural drainage.

3.3.4 URBAN DRAINAGE

The urban drainage network in Hue is probably one of the reasons why the SOBEK model shows flooding in the city where there was none. The urban drainage system in the city can roughly be divided in two parts. First there are 40 lakes in the Hue Citadel alone. These lakes store water and can facilitate drainage to other areas. Although the lakes are facing problems such as silting, clogged connections and declining surface area. The Urban water flow system can be seen in Figure 103.

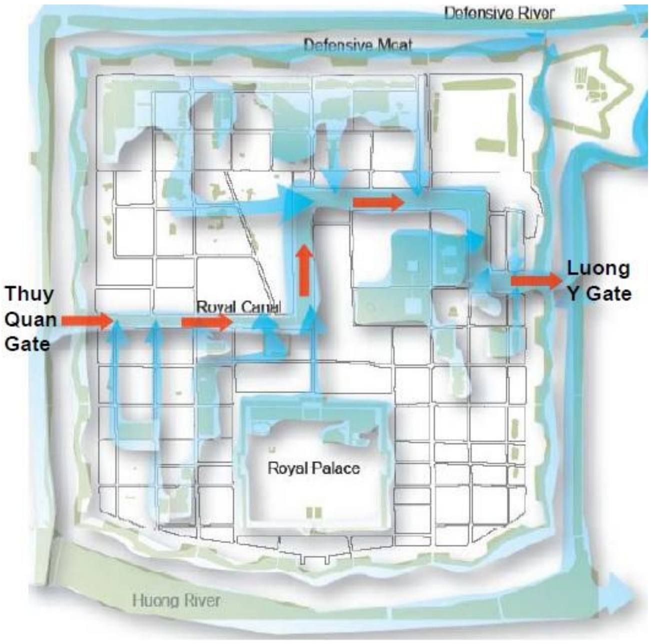


FIGURE 103: URBAN DRAINAGE FLOW SCHEME (LIEU)

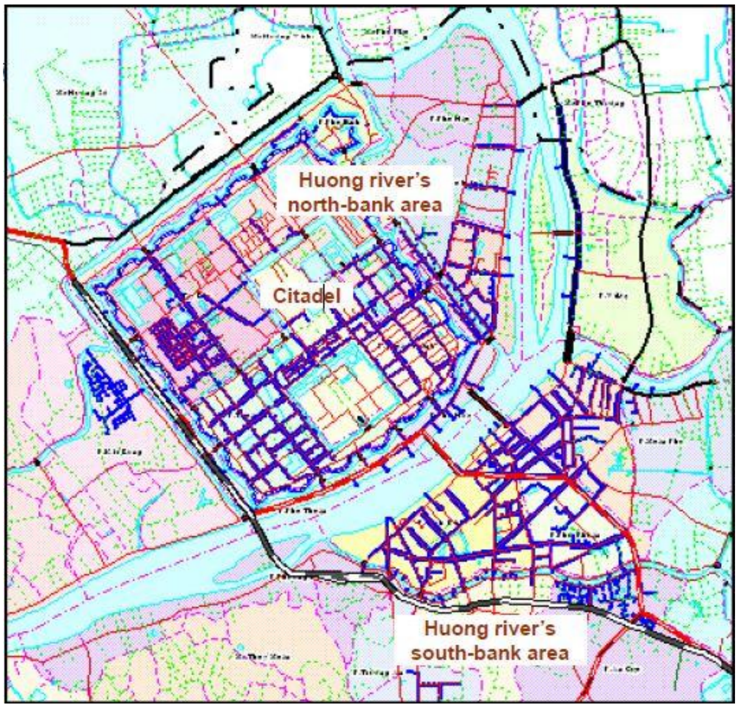


FIGURE 104: URBAN DRAINAGE NETWORK IN HUE CITY (LIEU)

A network of sewerage pipes increases the drainage capacity of the area. This network, shown in Figure 104, is a combined network. The characteristic of such a network is that both rainwater and wastewater are discharged in a single sewage system. The wastewater is for the most part coming from septic tanks and Sulabh systems in the area (Lieu). Renovation of the drainage network in the citadel will allow for a greater capacity. Additional research can indicate what system is best suited for this particular situation. It might be that a separate system can provide a solution to both rainwater drainage, and waste water pollution.

The urban drainage in Hue City is a significant part of the integrated water management plan for the province. Therefore, it is mentioned and described here. However, the influence of the two scenarios in this report is small. The small influence is that a reduced discharge in the Huong River will allow for easier flow out of the city.

3.3.5 RIVER MORPHOLOGY

Signs of erosion were clearly visible on the river banks of the Huong River. Both scenarios aim to reduce the discharge in the Huong River. Reducing the discharge also reduces the flow velocity, this reduces the erosion of the river banks. So both reservoirs will have a good impact on the erosion of the river banks, but still some erosion protection is recommended at some places. These are especially the places where the houses are built very close along the river.

3.4 FLOOD RESISTANANT BUILDINGS

To save lives and decrease damage it can be very helpful to make buildings which are able to resist floods. In flood resistant buildings, people are protected against a flood and/or the damage on the building due to a flood is decreased. With a flood resistance house the people can cope better when there is a flooding. So safety is not only to protect people with dikes (threshold safety), but also make buildings more flood resistant (coping safety). It will be hard to get a very high return period in the Thue Thien-Hue province due to its climate. In this chapter firstly is described how the houses are developed through the years in the area of Hue. After that some recent activities around Hue are described, which increase the resistance of buildings against floods. In section 3.4.3 some more possible improvements from all over the world are suggested which can make a building more resistant against floods. These improvements can possibly be implemented in the area around Hue. After discussing the current situation and possible improvements the observations during the field work will be discussed. In section 3.4.5 the possible solutions for the Thua Thien-Hue province will be discussed.

3.4.1 CURRENT STATE OF SHELTER CONSTRUCTION

In the Vietnamese culture the idea behind a house differs some from the western idea. Dr. Nguyen Huu Huy describes the term “house” as widely used in Vietnam for accommodation, but often also includes separate facilities such as kitchen, shop, workshop, and livestock pen. Vietnamese houses can be subdivided into the following three categories (Huy 2002):

- Traditional houses
- Modern solid houses
- Houses built with a mixture of different materials and by different techniques.

These three types of houses will be described in more detail in the following paragraph. The history, the function and the typical properties of all three different types of houses will be discussed.

TRADITIONAL HOUSES

Traditional houses are the oldest design of the three discussed house structures. The traditional Vietnamese houses in the north, the centre and the south all differ a bit from each other. In the region around Hue, the area this report is focused on, the traditional houses are called "Roi" and "Ruong". The Ruong design is the most common traditional structure of the two, in the central part of Vietnam. This structure is an improved Roi structure. The change from Ruong standard to the Roi standard is because of the development of planning and because the owners became richer. They wanted more space for living and they had the materials and conditions to make stronger and more beautiful houses.

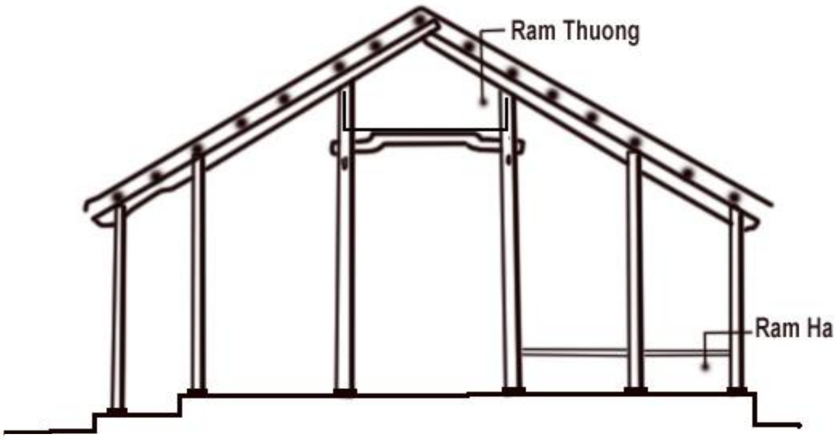


FIGURE 105: "RUONG" STRUCTURE WITH "RAM THUONG" AND "RAM HA", TYPICAL TRADITIONAL HOUSE IN HUE (NORTON AND CHANTRY 2002)

Typical for the "Roi" structures design (Norton and Chantry 2002):

- Wooden structures
- Middle columns in the design which increase the capacity of sustaining strength
- The Ram Thuong and the Ram Ha for storage and temporary residence in case of a flood
- The roof structure includes trusses and is connected to the ground with only the supported columns
- The columns are traditionally placed on the ground, so they are easy to remove to store and reinstall on new ground

The walls in the buildings only have the function to protect from rain, wind and sun.
In Figure 105, the typical design of a traditional house from Hue is shown. The typical middle columns and the Ram Thuong and the Ram Ha are also included in this design (Bach 2011).
Until the mid-eighties a typical village in the centre of Vietnam was a cluster of these traditional houses (Norton and Chantry 2002). Nowadays, there are almost no traditional wooden houses as the Ruong anymore. The most houses now are modern solid houses or houses built with a mixture of different materials and by different techniques.

MODERN SOLID HOUSES

The modern solid houses are quite similar to the same as the traditional houses. The major differences between both designs are:

- The walls of the modern solid houses are made of load-bearing masonry.
- The roof of the modern solid houses is made of reinforced concrete.

These houses are in general typhoon resistant. The real typhoon resistance of the houses of course depends on the quality of the construction.

HOUSES BUILT WITH A MIXTURE OF DIFFERENT MATERIALS AND BY DIFFERENT TECHNIQUES

Houses built with a mixture of different materials and made with different techniques, from now on called: mixed houses, are all the houses which are not traditional houses or modern solid houses. Most of the people living in these houses are poor people, who cannot afford a traditional wooden structure or a modern solid house with masonry walls and a reinforced concrete roof.

The mixed houses have a strong relation with the Vietnam War. During the war a lot of villages and towns were burnt and levelled, especially in the provinces in the North Central Coast. After the war people restarted their lives again with nothing. They had to rebuild a lot of structures like hospitals, schools and their own houses. Because for many people no materials were available, many people made their own shelters using locally available materials and applying traditional building techniques.

The problem of the mixed houses is that they are mostly not capable to resist typhoons and floods. There are two important reasons why the mixed houses are not typhoon and flood proof. The first reason is an economical one. The second reason is because of the lack of technical knowledge.

The economical cause of the bad mixed houses is hard to solve. A Vietnamese proverb says "one year to build a house, three years to pay the debt" (Huy 2002). So if a house cannot resist a typhoon which comes mostly a few times a year, it is impossible to break the cycle of debt and build a traditional wooden or modern solid typhoon resistance house. So the poor people living in these houses remain poor and probably can never afford themselves a better house.
Beside the reason people cannot afford themselves good building materials, people are not advised, supported or encouraged to apply technical knowledge to build their shelter. This is also a reason for the bad quality of their self-made houses. Some typical flaws are (Huy 2002)

- Building on unfavourable places, for example: exposed to wind, in open fields or at the shore
- Connection/ bracing between bracing trusses is missing
- Trusses are not firmly connected to the wall or the column
- Walls are not strong enough to transfer loading to the foundation

3.4.2 RECENT IMPROVEMENTS

Vietnam is already dealing to improve their buildings and houses. For the province of Hue, some research is already done in order to prevent typhoon damage to housings. A report of ESCAP from 2013 discusses how damage from typhoons to housings can be prevented with some simple measures. The idea behind is that simple measures are easy to implement, so the measures are relative cheap to apply. In the article, the next 10 principles are presented to prevent typhoon damage to houses (Figure 106):

1. Choose the location carefully to avoid the full force of the wind or flood.
2. Build a house with a simple shape to avoid negative pressure build up due to wind.
3. Build the roof at an angle between 30° and 45° to prevent it from being lifted off by wind.
4. Avoid wide roof overhangs; separate the veranda structure from the house.
5. Make sure the foundations, walls, roof structure and covering are all firmly fixed together.
6. Reinforce the triangular bracing in the structure; strengthen walls to increase stiffness.
7. Secure the roof covering to the roof structure to prevent it being lifted off by wind.
8. Match opposing openings in each room.
9. Use doors and windows/shutters that can be firmly closed.
10. Plant trees around the house as wind breaks and to reduce the flow of water.

FIGURE 106: TEN PRINCIPLES TO PREVENT TYPHOON DAMAGE ON HOUSINGS (ESCAP AND AIT 2012)

The first indicator of the success the principles is the ability of houses to withstand typhoon Xangsane from 2006. This typhoon damaged about 20.000 houses and unroofed another 275.000 houses in the three central provinces alone. In the most affected areas almost all houses were damaged severely. Only 5% of the houses built with the 10 principles suffered any or even very minor damage. Even the people who live in the houses mentioned that the damage to their houses was smaller than any of the houses they built before.

The local government which was firstly quite sceptic about the program of the 10 principles, changed their attitude after the typhoon of 2006. Before the typhoon they did not believe it was possible to strengthen the weak houses of the poor people. But after Xangsane they were such enthusiastic that they support the principles and apply them for more houses.

In Figure 107 and Figure 108 a clear comparison is shown between a non-typhoon proof house and a house which can resist a typhoon better. In Figure 108 are the principles of Figure 106 applied. A few big differences:

- Concrete covering on the roof structure to prevent it being lifted off by wind
- The walls, roof structure and covering seems all firmly fixed together
- There are doors and shutters can be firmly closed.

FIGURE 107: NON-TYPHOON PROOF HOUSE (NORTON AND CHANTRY 2002)

FIGURE 108: BETTER TYPHOON PROOF HOUSE (NORTON AND CHANTRY 2002)

3.4.3 POSSIBLE IMPROVEMENTS

There are different ways to make a building flood resistant. In this chapter are a few ways described. A difference is made between solid buildings, and floating buildings. First a few measures are described for houses which cannot float. After that some designs of floating buildings are presented.

SOLID BUILDINGS

A solid building in Vietnam is the modern solid building mentioned earlier. These buildings can be protected against the flood for example by dikes or can resist the flood water level. A paper of Kreibich presents three building precautionary measures. This report results in some building precautionary measures as shown in Figure 109, which may mitigate losses in flood prone areas (Kreibich, Thieken et al. 2004):

Implementing these measures can be quite expensive. Only with a favourable cost-benefit ratio the measures can be implemented easily.

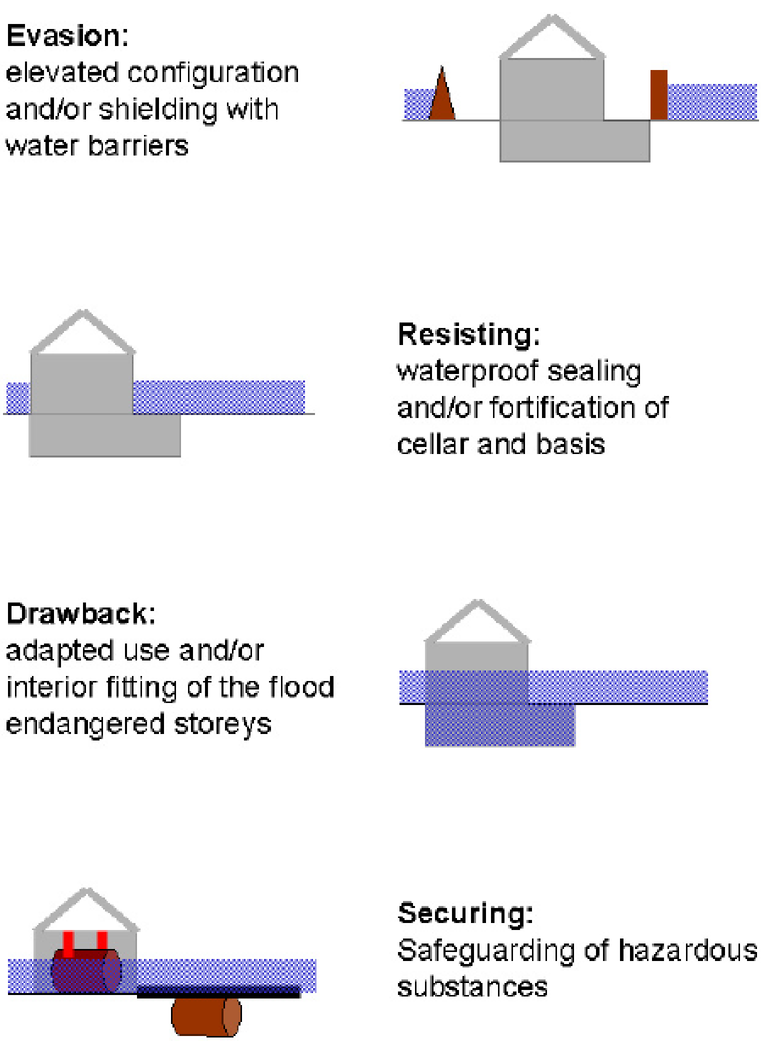


FIGURE 109: OVERVIEW OF DIFFERENT BUILDING PRECAUTIONARY STRATEGIES AND MEASURES (KREIBICH, THIEKEN ET AL. 2004)

All the measures introduced in Figure 109, will be explained in a little more detail.

Measures with evasion make sure the flood will not reach the building. This is a quite classical way. The building can be elevated such that the building is always higher than the water level in a flood or a building can be shielded by water barriers like dikes. These water barriers can be permanent or mobile. Water barriers can take a lot of space, for example big dikes, which is often quite undesirable in urban areas. Mobile water barriers are only effective if there is enough time to place them. So an early warning system for a flood is required to apply mobile water barriers in an effective way.

If resisting measures are applied the water comes till the outside of the building but will not enter the building. This means that the building materials of the outside have to be waterproof or coated. Stability of a waterproof

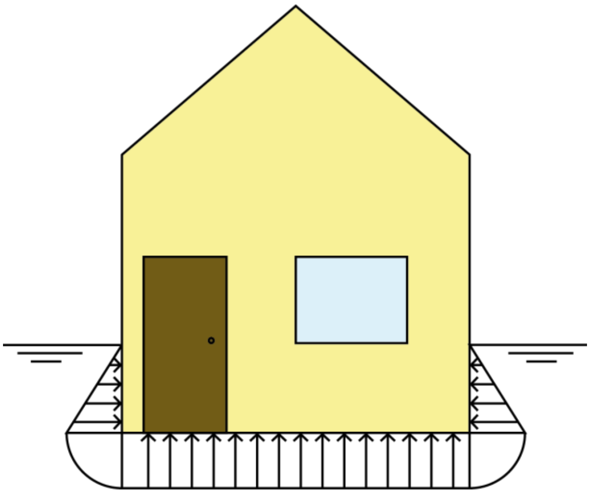


FIGURE 110: WATER PRESSURE DURING A FLOOD

building can be a problem if the water level is too high. When groundwater rises above the foundation of the building, the walls and basis of the buildings are exposed to buoyancy forces and water pressure. Also erosion and washing out of free-standing elements can give stability problems. Normally, buildings are not designed on buoyancy forces and water pressure. Therefore, the water level outside the building cannot be too high. Else the building will not be stable anymore, which gives even more damage. As a general rule, the maximum height of waterproofing should be approximately one meter above the ground, unless further structural building improvements were undertaken (Kreibich, Thieken et al. 2004). The exact height of the water level depends on exact dimension of the building and the design of the building. For example, the way the foundation is designed and built, the weight of the building and strengthening of the building material.

When the water level is too high the building will become unstable. Then, it is better to let the water enter the building. Damage due to the entered water can be reduced as much as possible by flood adapted building use and interior fitting. This means that in the flooded storeys, most of the time only the first floor, must be built with waterproofed material and on this floor only small movable interior should be used. Non-waterproof installations like heating or water supply installations should be designed in a flood-proofed way or placed in the upper storeys.

The last measure is about the safety and secure storage of oil and other hazardous substances. The tanks where the oil is stored in can mostly float in water, since oil is lighter than water. So for floods the tanks must be designed against buoyancy forces. Furthermore, the tanks have to be designed against water pressure, if the tank is assumed to stay under water.

FLOATING BUILDINGS

In the waterproof designs mentioned above, the house is the basic and is protected against water or the water damage is prevented as much as possible. Another option is to build on piers or to build floating buildings. Then during a flood the houses are not between water mass, but above the water (some limitations neglected). There are two building types. First, building on piers is already a quite classic solution, but can be still very effective. Secondly, solutions and designs consisting of floating building are still under development.
In this chapter both designs are described. The description starts with a 'normal' solid house and hereafter a floating and flood resistant building is described with a few modifications in the design. The 'normal' solid house on the figures is not a real Vietnamese house, but it is good

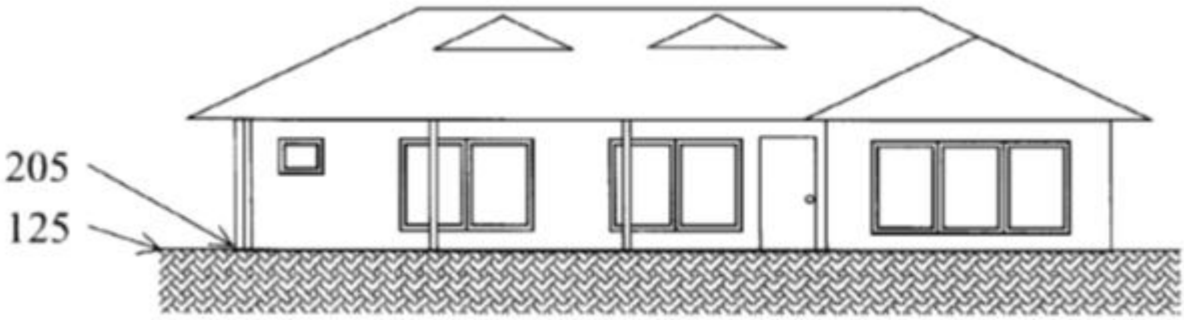


FIGURE 111: 'NORMAL' SOLID HOUSE WITH FLOOR LEVEL ON THE SAME LEVEL AS THE GROUND LEVEL (DAVIS 2002)

enough for the comparison.

DESIGN 1: DAVIS

Figure 111 shows a graphical representation of a 'normal' solid house as it is usually built in the USA (Davis 2002). The floor level of the house (205) is at the same level as the ground level (125). In a flood-prone area this type of building is less desirable, because flood waters of any depth is higher than the floor level.
An old solution for houses in flood prone areas is to build the superstructure (105) on piers (Figure 112). If the piers (115) are for example one meter high, the flood water will not enter the house if the flood level is lower than one meter above the ground level (125). To stabilize the construction the construction is braced (120). Davis numbers a number of specific disadvantages for the design of Figure 112:

- Flood waters may advance higher than the raised floor level (110);
- The fixed piers (115) may be unsightly, especially if they are relative high to deal with correspondingly high potential flood water situations;
- Building regulations may place restrictions on maximum roof or floor heights, which can prevent sufficiently long piers being used;
- In very low-lying areas or areas prone to deep flooding the required pier height can be considerably higher than is desirable given the need for day-to-day asses for residents.

Concluded from this design with Davis' disadvantages: the buildings on piers are only desirable if the piers are not too high.

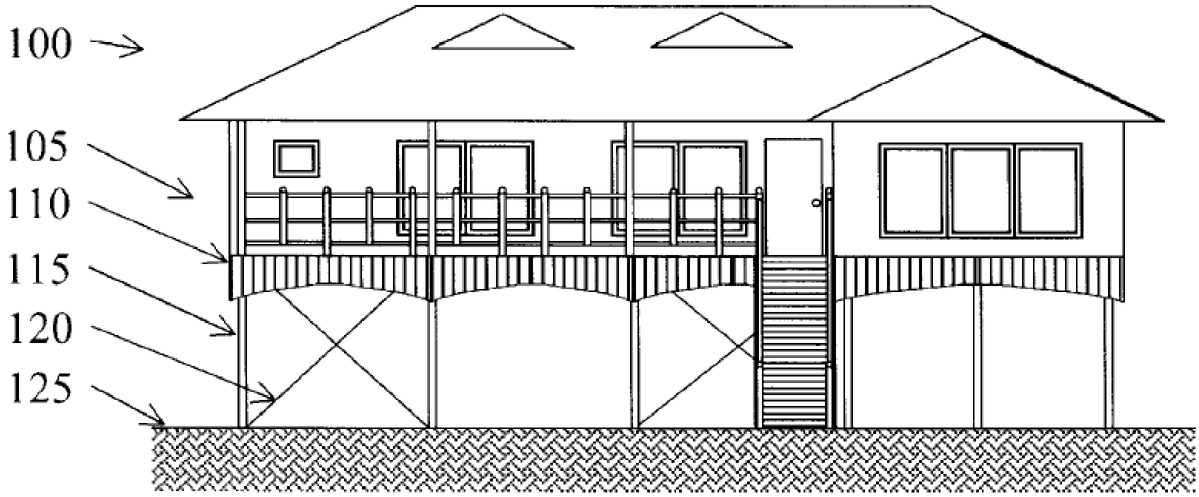


FIGURE 112: HOUSE ON PIERS (DAVIS 2002)

DESIGN 2: WINSTON

Another option suggested by Winston is showed in Figure 113 (Winston 1994). The most interesting parts in the figure are 'the floor system with flotation elements' and 'the foundation'. First some remarks about the floor system with flotation elements:

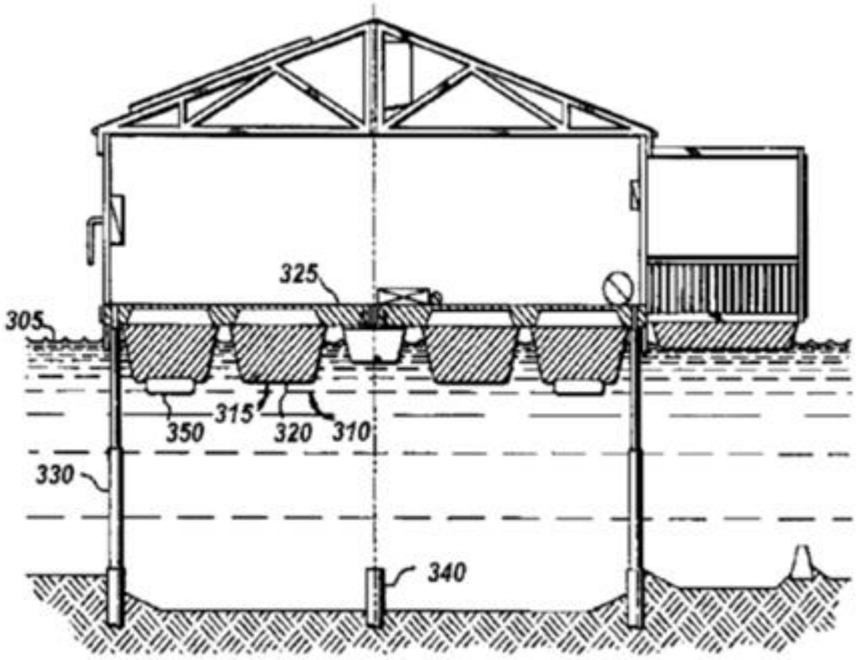
- There are four (depending on the dimensions) flotation elements (320) with foam filling (315) for flotation capacity and plastic cover (320) for more durable elements.
- Wooden beams for the floor system to reduce weight (325)

The other interesting aspect is the foundation. The foundation exists of two different piers:

- Telescopically extendible piers (330) for the wet and dry season
- Solid wooden pilings (340) for the dry season only.

During a flood the flotation elements take up all the vertical forces from the house. This means that the telescopically extendible piers only have to make sure the house is not floating away by the wind or water. Only a few piers are needed to hold the house in place, so only a few piers have to be telescopically, which reduces the costs of the building.

During dry season the solid piers and the telescopically extenible piers together lead the vertical forces from the house to the foundation.



305 – Floodwater level

310 – Flotation elements

315 – Foam (filling)

320 – Plastic liners

325 – Wooden beams

330 – Telescopically extendible piers

340: Wooden pilings (dry-land foundation)

350: Air bladders

FIGURE 113: PREFABRICATED MODULAR HOUSING UNIT(WINSTON 1994)

The design from Figure 113 has a few disadvantages:

- Extendable telescopic piers are exposed even in retracted position and can be subjected to ingress of moisture and dirt over time.
- The piers can corrode
- During a flood, water fills the extended telescopic piers, apparently to provide a damping effect.
- Foam filled plastic liners are potentially prone to degradation of the long term.
- The housing unit is unstable when it floats and requires careful balancing of loads.

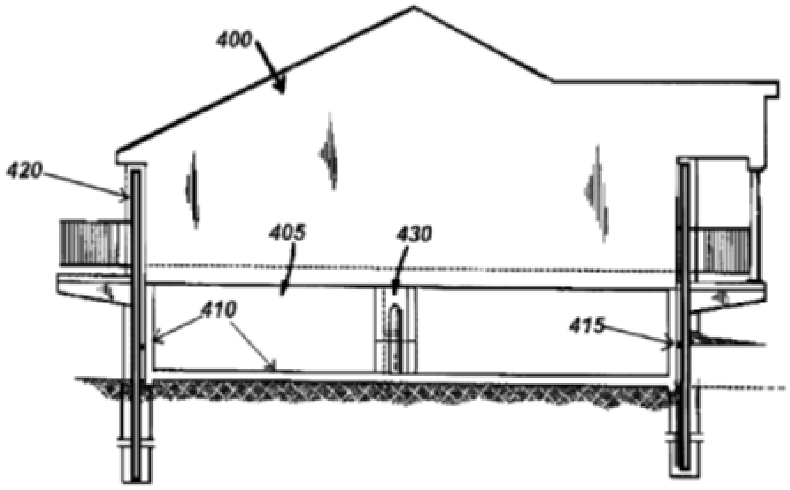
The last point about the unstable house when it floats is a quite important one. The load distribution depends a lot on the way the building is furnished. To compensate the uneven load distribution and shifting loads during a float, air bladders (350) are installed in every corner of the house. The air bladders can be filled with air to keep the building stable during a float. Unfortunately the design with the air bladder is quite complex, inefficient and time consuming as it requires a compressor, a level measuring device and fine tuning.

In short, the most important aspects to be improved:

- Durability of the telescopically piers
- Durability of the flotation elements.
- Stability of the building

DESIGN 3: CARLINSKY

Another technique to construct a floating building is designed by Carlinsky. Carlinskys design is showed in Figure 114. Special aspects of this design are the pressurised cylinders.



400: Prefabricated building
405: Watertight basement
410: Floor and walls (unitary concrete constriction)
415: Rollers
420: Guiding system
430: Pressurised cylinders

305: Floodwater level
310: Flotation elements
315: Foam (filling)
320: Plastic liners
325: Wooden beams
330: Telescopically extendible piers

FIGURE 114: PREFABRICATED BUILDING BY CARLINSKY (DAVIS 2002)

This design is almost the same as the previous one, the big differences are:

- The added guiding system in the second design
- Pressurised cylinders in the second design

The added guiding system is quite a simple system which is not explained further here.
The job of the pressurised cylinders is to lift the building prior to a surge of floodwater and for breaking any vacuum as the building first lifts under the influence of floodwater. This new system also brings new problems. In Davis patent a few disadvantages are mentioned:

- To reposition the building at ground level after even after a minor flood, it is necessary to deploy lifting mechanisms at several points around the building perimeter.
- Carlinsky does not disclose the manner in which the buoyancy forces generated during a flood are transferred from the unitary basement structure (405) to the rest of the building.
- The Carlinsky system is cumbersome and potentially unreliable.

CONCLUSIONS

After analysing two floating systems, some other serious disadvantages can be called for both systems:

- Uppermost limit of travel
- Buoyancy forces continue to rise
- All debris collected under the basement during a flood must be removed before the building can be lowered into its normal position.

In Davis patent mentioned three possible scenarios to deal with the first and the second problem, uppermost limit of travel and buoyancy forces, but none of them is a really good solution. Further research should be done to have a solution for these big disadvantages.

3.4.4 OBSERVATION DURING FIELDWORK IN THE THUA THIEN-HUE PROVINCE

To observe the houses a few things get special attention. Those things were spotted during the fieldtrip in the Thua Thien-Hue Province:

- The way the walls are made, especially the finishing.
- The level of the floor with respect to street level.
- The furnishing of the first floor.
- Special structures like floating houses.

These attention points do all come back in the literature study. The walls are important for water permeability to apply the resisting tactic, the level of the floor for some reference of the flood level, the furnishing of the first floor for the drawback tactic and special structures are interesting to determine what special structures are already in the area and how they are implemented.

During the observations a few things about the buildings and especially about houses stood out:

1. The level of the first floor is often quite higher than the level of the ground.
2. The walls of the most houses are made of bricks covered by a cementitious layer of about 1 – 2 cm.
3. In the area from the floor level until about 1,0 meter above floor level are almost no gaps for ventilation, air conditioner or something like that.
4. There is almost no interior at the first floor in many houses. Only the necessary interior like chairs and table were there.
5. Electrical outlets are often placed relative low on the wall.

All these observations will be discussed in more detail. Many buildings already have a design which minimizes the damage of a flood but there is still room for some improvements. Combining the observations with the literature study done before, allow for a few simple recommendations to be made. These recommendations will be done in section 3.4.5. In 3.4.4 the observations will be discussed.

FIGURE 115: TYPICAL VIETNAMESE HOUSE WITH THREE STEPS FOR THE DOOR

OBSERVATION 1: THE LEVEL OF THE FIRST FLOOR IS OFTEN QUITE HIGHER THAN THE LEVEL OF THE GROUND

The first observation about living on higher places is a very classic one, but it is still effective. The most common buildings in the province of Hue have a high foundation which is often 2 or 3 steps higher than ground level, and a fence about 1.2m high (Han 2011). In Figure 115 is such a common building is shown with a three steps stairs above ground level. This building is placed in an urban area. There is no fence around the house, because of the lack of space in the urban area. As a general rule, it is saver to assume that the foundation is 2 steps higher than ground level instead of 3 steps. The steps are about 20cm. So a two steps stair is about 40cm high. That makes the general rule that the level of the foundation of the houses is 40cm higher than ground

OBSERVATION 2: THE WALLS OF THE MOST HOUSES ARE MADE OF BRICKS COVERED BY A CEMENTITIOUS LAYER OF ABOUT 1 – 2 CM

The second observation, about the brick walls with a cementitious layer, is very helpful using the resisting tactic described in the report of Kreibich.This principle is already explained in the literature study. The principle of the resisting strategy is again schematically shown in Figure 116. Figure 117 a brick wall with a cementitious layer is shown in the building stage. It is clearly seen how the wall is made. First the orange bricks are cemented. After that the cementitious cover is applied over the brick walls.

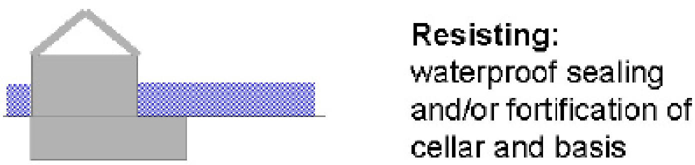


FIGURE 116: RESISTING PRECAUTIONARY STRATEGY

The cementitious cover is around 1 or 2 centimeters thick. To be on the save side, 1cm thick cover is assumed. It is also assumed that the layer of 1cm of cement is non-permeable. Now the wall can be assumed as impermeable. So it is assumed that if there is a flood, the water does not enter the building through the walls.

OBSERVATION 3: IN THE AREA FROM THE FLOOR LEVEL UNTIL ABOUT 1,0 METER ABOVE FLOOR LEVEL ARE ALMOST NO HOLES FOR VENTILATION OR AIR CONDITIONING.

The third observation is about all the holes in the walls except doors. Holes can be caused for example by air conditioners, ventilation gaps or windows. Mostly the gaps are placed higher than 1.0 meter above the foundation level which is favourable if the method of resisting from Kreibich is used (Figure 109). So it seems there are no problems there. If this tactic of resisting is used in the future, buildings should also be built such that there are no gaps at the height between the foundation and 80cm above the floor level.

Water during a flood can not only enter a building via gaps in the wall, but also via the sewer and the toilet. For simplicity this report will only be focussed on the toilet and not on the sewer. Measures should be taken to prevent this, because the strategy of resisting can only be applied if

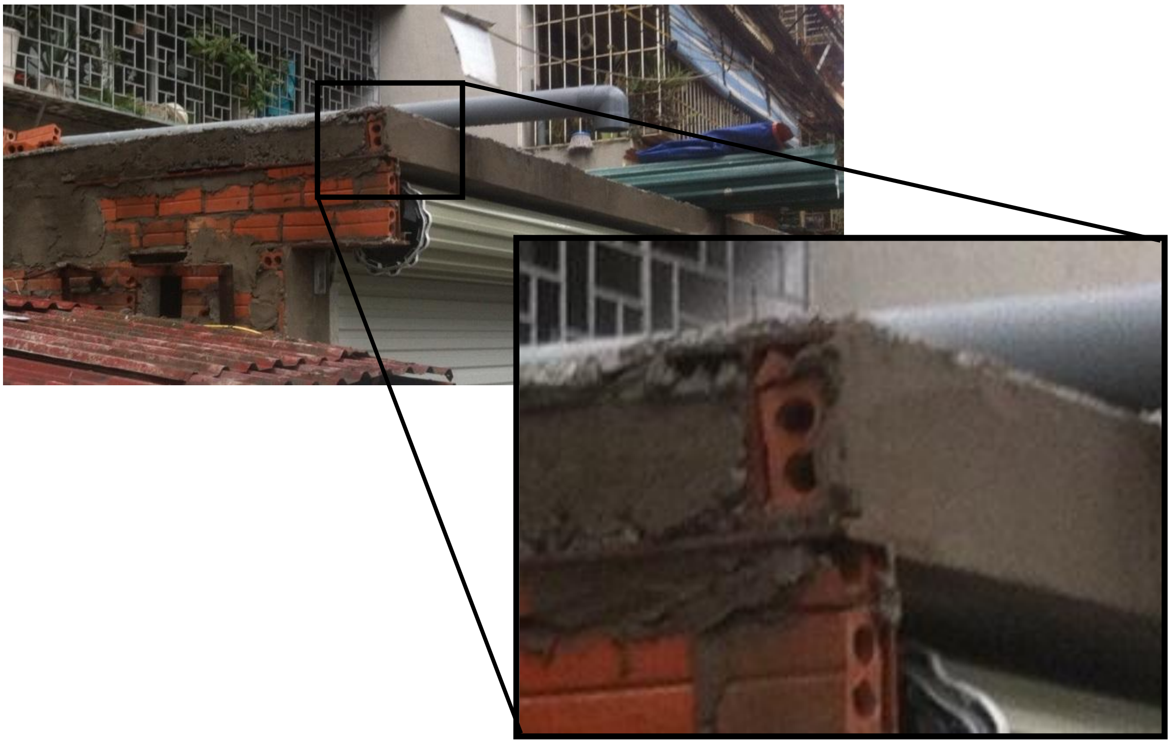


FIGURE 117: TYPICAL BUILT WALL OF A VIETNAMESE HOUSE

all the ways the flood water can enter the building are closed. These measures should be simple but effective to implement. More attention to this will be given in the next chapter.

From the observation it can be concluded that the walls are suitable for the resisting strategy if the doorways can be closed in a water tight way. Measure should be taken for the toilets, to prevent water from entering the house via the toilet.

OBSERVATION 4: THERE IS ALMOST NO INTERIOR AT THE FIRST FLOOR IN MANY HOUSES. ONLY THE NECESSARY INTERIOR LIKE CHAIRS AND TABLE WERE THERE.

The fourth notable aspect of the houses is about the interior and the finishing of the walls at the first floor. In the literature is already spoken how the first floor should be furnished to prevent as much damage as possible if flood water enters the building. The interior should be small such that it can be placed to an elevated place during a flood. This elevated place can be the second floor in case of a solid house or the 'Ram Thuong' in case of a traditional wooden house. In many houses the interior at the first floor consisted of some chairs, a table and a television in the living room. This interior is quite easy to place to a flood save place. Conclusion from this observation is that the first floor of the most houses is already furnished to prevent as much damage as possible if the water enters the house.

OBSERVATION 5: POWER POINTS ARE OFTEN PLACED RELATIVE LOW ON THE WALL

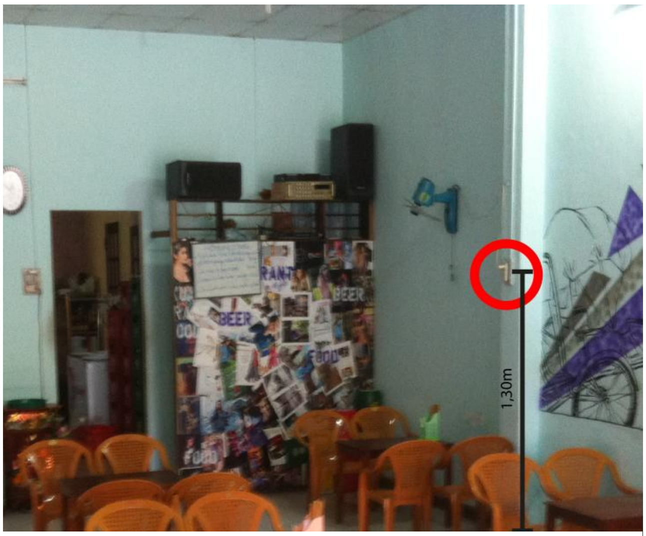


FIGURE 118 : POWER POINT AT THE FIRST FLOOR

The last point is about the electrical outlets. These outlets are often placed at a low elevation. Figure 118 shows a good example of outlets at the first floor of a building. Assuming the height of the door is around 2.0m the electrical outlet is placed around 1.3m above floor level. An electrical outlet combined with flood water creates an undesirable situation. So it is desirable to prevent the outlets from flood water as much as possible. The most logical solution should be to place the outlets as high as possible. The problem with high placed outlets is that it is not user friendly. In the next chapter is this issue spoken in more details.

All the conclusions from the field work are listed together. There is made a difference between conclusions which are favourable against floods and conclusions which are unfavourable against floods.

Favourable:

- The level of foundation of the most houses is built 40cm higher than the ground level.
- It is assumed that if there is a flood, the water cannot enter the building through the walls.
- Mostly the gaps are more than one meter above the floor level, so the method of resisting from the paper of Kreibich can be used
- In many houses the interior at the first floor is easy to remove before a flood occurs.

Unfavourable:

- Water which enters the house through the doorway has to be stopped to apply the strategy of resisting; a solution has to be found.
- Water which enters the house thought the toilet has to be stopped to apply the strategy of resisting; a solution has to be found.
- Electrical outlets are placed quite low, so flood water can easily come into the outlets.

From the observation can be concluded that the houses are already quite well designed to resist flood water, but there is still some room for improvements. These improvements can be turned into three goals. The three goals are:

- Prevent flood water enters the house through doorways.
- Prevent flood water enters the house through the toilet.
- Prevent flood water comes to the electrical outlets.

In the next section some possible solutions for these goals will be discussed.

3.4.5 IMPROVEMENTS OF THE HOUSES IN THE THUA THIEN-HUE PROVINCE

In this chapter is discussed how the three goals from the previous chapter can be improved. The three goals are:

- Prevent flood water from entering the house through doors.
- Prevent flood water from entering the house through the toilet and sewer.
- Prevent flood water from reaching the electrical outlets.

For each goal some alternatives are designed, which are discussed in detail. For the first two goals, the best alternative is recommended by a Multi-Criteria-Analysis. For the third goal, just two simple options are named.
The most Vietnamese people living in the flood prone areas are not that rich, because they started with nothing after the Vietnam war (Huy 2002). Because of that complex and expensive implementations are hard to apply. So designs should be simple and cheap.
These two boundary conditions, simple and cheap, make that solutions with floating buildings won't be implemented. These kind of buildings normally costs more than a common solid building. Also these buildings are technically quite difficult to make, where simple solutions are needed. So the focus lies on the three goals listed above without the implementation of floated buildings.

GOALS A: PREVENT FLOOD WATER ENTERS THE HOUSE THROUGH DOORS

The obtained information collected during the field trip, one can conclude that with a small adoption in the doorway a principle invented by Bramley can be implemented easily(Bramley and Bowker 2002). In Figure 119 and Figure 120 doorway barriers are showed; in the left figure

FIGURE 120: DOORWAY BARRIER IMPLEMENTED IN TYPICAL VIETNAMESE HOUSE (Bramley and Bowker 2002)

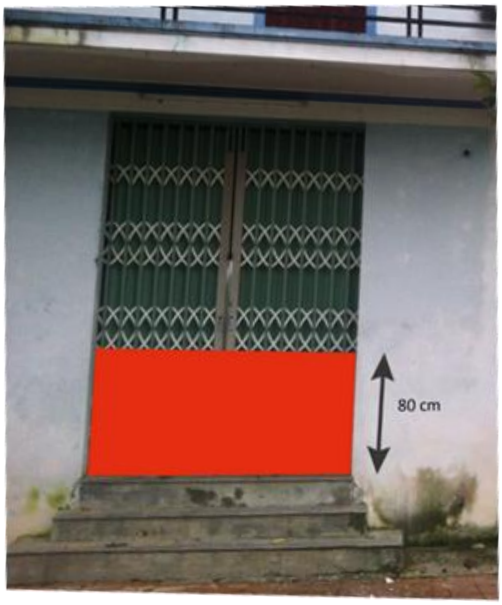


FIGURE 119: DOORWAY BARRIER IMPLEMENTED IN TYPICAL VIETNAMESE HOUSE

a doorway barrier applied somewhere in Europe and in the right figure is schematically shown how a doorway barrier could be applied in Vietnam. In Bramley's report is described that the general rule that the water level during a flood should not be higher than one meter above the foundation of the house. This general rule is applied for European houses. Let assume that this general rule can be transformed to Vietnamese houses with a reduction of 80% to be on the save site. Vietnam is a second world country, so it seems to be a good assumption that the quality of the buildings is not as good as in Europe. Further, the houses in Vietnam are less heavy then the houses in Europe. So less buoyancy forces are needed to make the house unstable. With this assumption made, the maximum height to implement a doorway barrier is about 80cm above floor level of the house. An impression of such a door barrier is shown in Figure 121.

From the literature study and the fieldtrip is concluded that most of the houses are 40cm above the ground level. So if the doorway barrier of 80cm high is applied, the flood water can come until a height of 120cm above the ground.
Before the design is done, some requirements are determined:

- The height of the barrier is 80 cm.
- The connection between the barrier and the walls has to be water tight.
- The connection between the barrier and the floor has to be water tight.
- The barrier has to be temporary, such that the doorway can be used normally during the dry season. So the barrier has to work during flood and must not have negative side effect for during the dry season.
- The costs of the barrier system should be lower than the benefits.
- The barrier has to be durable.
- The barrier must be simple to apply, which reduces the costs.
- The barrier should be easy to use such that non-educated people can use the barrier in a proper way.

FIGURE 121: IMPRESSION OF A DOOR BARRIER

In this chapter the costs of the barrier will not be discussed, because there is not enough information to say something useful. Assumptions can be made, but too many assumptions have to be made with too little information for a realistic conclusion.
To determine if the benefits outweigh the costs of the design, a cost-benefit-analysis should be made. Additional research could indicate whether such a cost-benefit-analysis comes out positive.
The doorway barrier is shown in Figure 122. The height of the barrier is 80 cm. the cross section lines AA and BB are also drawn in the figure. The design alternatives for the doorway barrier are explained with figures of the front view and the cross sections AA and BB. In the front view is explained what the doorway barrier will be look like. In cross section BB is shown how the barrier is placed between the two walls. In cross section AA is shown how the barrier can be connected with the ground.
Let's start to discuss the design with the front view of the doorway barrier of Figure 123. The barrier itself (blue square) is a thick plate. The barrier is a temporary construction. During a flood the barrier can be placed in the doorway between two guiding rails. When there is no flood, the barrier itself can be removed completely and stored somewhere in the house. To put the barrier in place during a flood, it just has to be put down between the guiding rails.

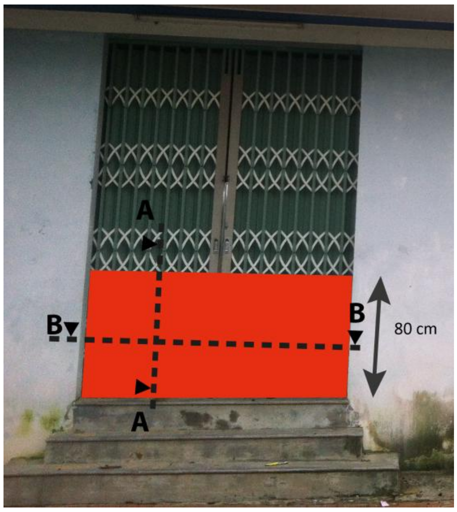


FIGURE 122 : DOORWAY BARRIER WITH CROSS SECTION DIRECTION AA AND BB, FRONT VIEW

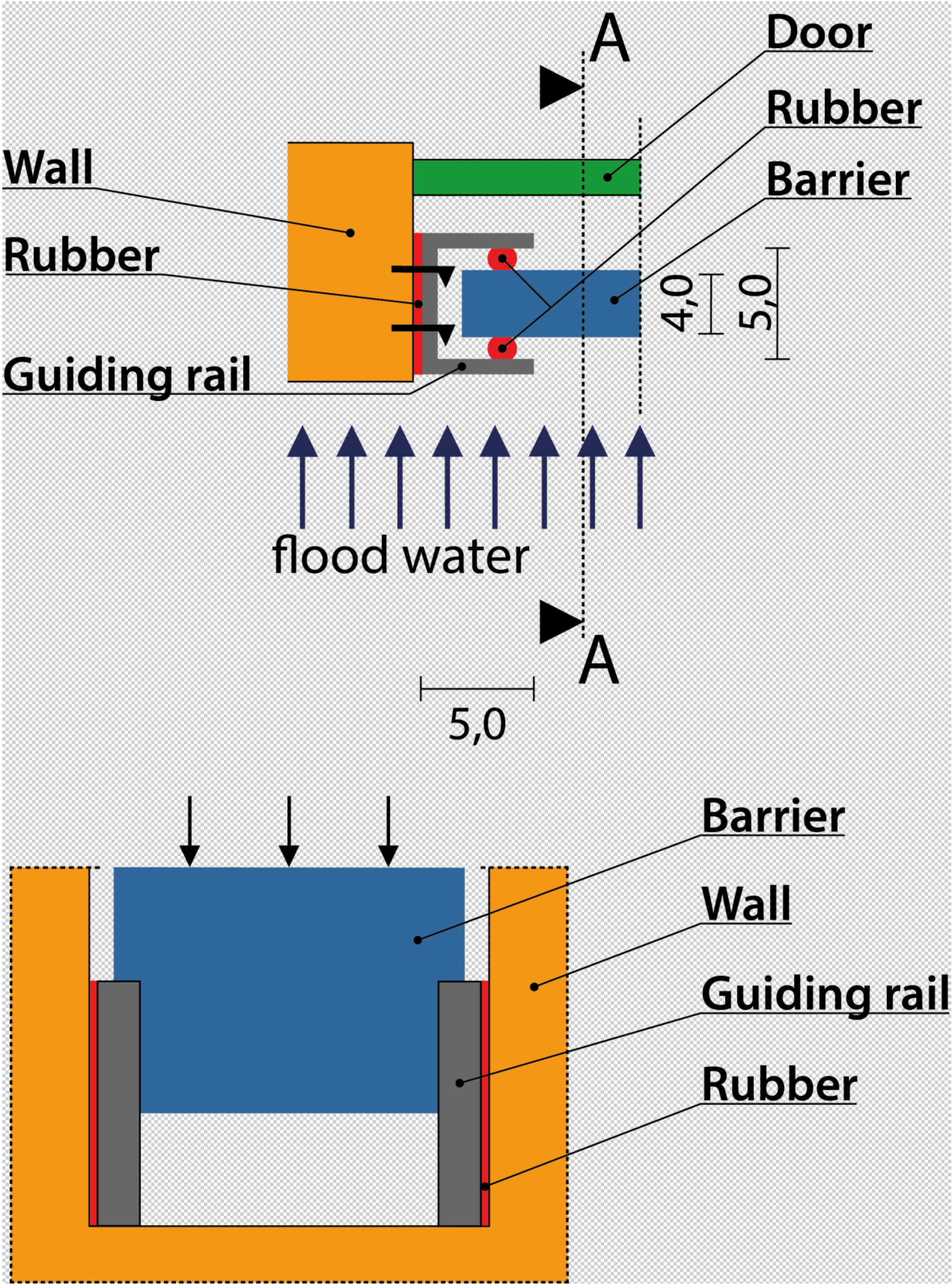


FIGURE 123: THE TOP AND SIDEVIEW OF THE DOORWAY BARRIER (DIMENSIONS ARE IN CM)

The guiding rails and the rubber strips between the wall and the guiding rail are permanent parts of the system. The guiding rail system is to guide the barrier when the barrier is brought into place and holds it in place during a flood. The rubber strips make the connection between the guiding system and the wall water tight.

Cross section BB is shown in Figure 123 (see also Figure 122) to explain the guiding system in more details. In the figure all the elements from Figure 123 can be recognized again.
The grey guiding rails are the connection between the barrier and the walls of the building. The guiding rail is connected to the wall with screws in plugs. To make sure the connection between the wall and the guiding rail is water tight, a rubber layer between the wall and the guiding rail is applied. This rubber layer has to be approximately 0.5cm to 1.0cm thick and has to be applied over the whole length of the guidance rail and the whole width or at least over the width between the screw rows.

The barrier itself is also with rubber strips connected to the guiding system. This strip is also approximately 0,5 cm to 1,0 cm. The rubber strips now have three functions:

- Holding the barrier in place during the flood.
- Make a water tight connection between the guiding system and the barrier.
- Prevent damage to the barrier if the barrier shifts in place. This makes the design more durable.

These three functions are explained more. Let's start to discuss the first function in more detail. If the barrier is between the strips and the water level is not raised yet, the barrier is clammed between the strips. This makes sure the barrier is hold in place the whole time.

The second function of the doorway barrier is to make a water tight connection. If the water level is not so high, the barrier can be modelled as clamped between the rubber strips in the guiding rails. As long as the barrier is modelled as clamped, the connection between the rubber and the barrier will be water tight. If the water level rises until the upper edge of the barrier, the water from outside presses the barrier to the inner placed rubber strip. This makes the connection between the rubber strip and the barrier even stronger and more water tight.

To have a durable construction, damage should be prevented as much as possible. The rubber strips will also have the function to prevent damage. If the barrier is shift down between the guiding rails, the rubber strips act like a pad. This prevents a lot of damage to the barrier, assuming that the guiding rails are made from a hard material like steel.

DESIGN FLOOR CONNECTION

To connect the door barrier with the floor three alternatives are designed. All options will be discussed in detail and rated with the requirements for the floor system. Requirements especially applied for the floor system are:

- The connection between the barrier and the floor has to be water tight.
- The barrier has to be durable.
- The barrier must be simple to apply.
- Ease of use

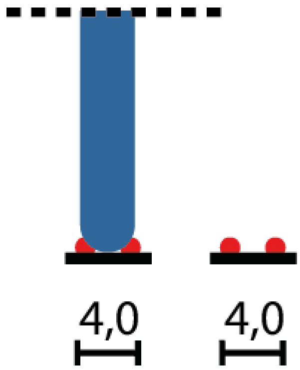


FIGURE 124: DOORWAY BARRIER OPTION 1, CROSS SECTION AA (DIMENSIONS IN CM)

OPTION 1

The first option is presented in Figure 124. At the left side of the figure is the system working during a flood and at the right side is the system if there is no flood. This option is the simplest option of all three.

The barrier is rounded at the edge such that it is very easy to shift it down through the guiding system and to prevent damage during placing the barrier. To make a water tight connection with the floor rubber strips are applied. The rounded edge must fall exactly in between the two rubber strips, which will make sure the watertight connection. The real water tightness of the connection depends on how hard the barrier is pushed against the rubber strips at the floor. This depends on the rubber strips in the guiding system. If the barrier is clamped between the rubber strips of the guiding system, the friction between the rubber and the barrier is very high. If the friction is high, the barrier will be kept in place. If the barrier is not clamped well between the rubber strips of the guiding system, the friction is low and the barrier can move easily. The connection between the barrier and the floor then won't be water tight anymore because the connection is not close anymore. Concluded, the water tightness of the connection in the floor depends on how good the barrier is clamped in the guiding system.

Another disadvantage is the durability of the option. During the dry season the rubber is exposed. So the strips can easily be damaged by people walking over the strips and the sun. The strips will become more brittle if the sun shines on them. The more brittle strips become, the more damage occurs when people step on them.

The big advantage of the first option is that it is very easy to make in existing houses. Only two rubber strips have to be installed upon the floor and then the floor connection is ready. The simple execution of the option makes the option also quite cheap.

In short all advantages and disadvantages again:

Advantage:

+ Easy to apply in existing buildings
+ Rounded edge makes it easy to shift through the guiding system

Disadvantage:

- Not very durable
- Water tightness is not guarantied

OPTION 2

In option 2 is tried to design some solutions for the disadvantage of option 1. Option 2 is shown in Figure 125, where at the left is the situation during a flood where the barrier is put between the guiding rails and at the right is the situation when there is no flood. The rubber strip is designed a few centimeters under the concrete floor. The advantages and disadvantages of this design will be discussed in detail here.

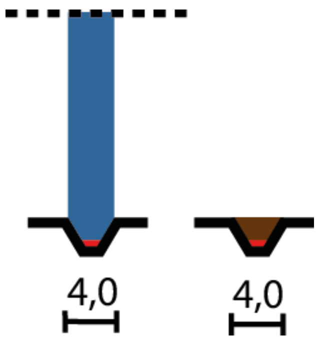


FIGURE 125: DOORWAY BARRIER OPTION 2, SECTION AA (DIMENSIONS IN CM)

The first disadvantage is again the water tightness of the connection. This again depends on how good the barrier is clamped in the strips of the guiding system. So the water tightness of both option 1 and option 2 will probably be comparable.

The second disadvantage of the system is that it is quite hard to apply in existing buildings. The rubber strip is placed a few centimeters in the concrete under the floor level. So in an existing building first a groove over the width of the barrier should be made in the concrete before strips can be installed. This makes this alternative relative expansive compared with the first option.

The big advantage to put the rubber strip a few centimeters under the concrete floor level is that it can be covered if there is no flood. Thanks to the cover over the rubber strip, damage caused by people or the sun is prevented. This makes this option very durable. The cover over the rubber strip can be made of different materials. The material should be even at the bottom side to prevent as much as possible damage to the rubber. A good material should be wood or plastic. The advantage of wood over plastic is that wood is probably cheaper. The advantage of plastic is that it can close the gap in the floor in better. Wood keeps reforming during its service life, so it will never connect as close to the concrete floor as the plastic can.

The last advantage of this option is about the ease of use. The corners at the bottom edge are cut off in this option. This makes it easier to shift the barrier down through the guiding rails. Furthermore, the cut off corners also prevent damage to the rubber strips. There is chosen for an angled cut off instead of a smooth round edge because the angled shapes are easier to make. The easier it is to make, the lower the chance that the barrier doesn't fit in the groove in the concrete floor.

Advantage:

+ More durable than option 1
+ Cut edge makes it quite easy to shift through the guiding system (Ease of use)

Disadvantage:

- Hard to implement in existing buildings
- Water tightness depends on how good the barrier is clamped in the strips of the guiding system

OPTION 3

The third and last option is shown in Figure 126. In this option it is tried to solve the problems with the non-water tight connections of the previous two designs. The rubber strip (red line in Figure 126) again is situated under the floor level, just like in option 2. The design is asymmetrical and will only work properly if it is made in the right orientation. For the orientation the side with the big circle, the left side in Figure 126, is the flood water side. So the other side is then automatically the side of the inside of the house.

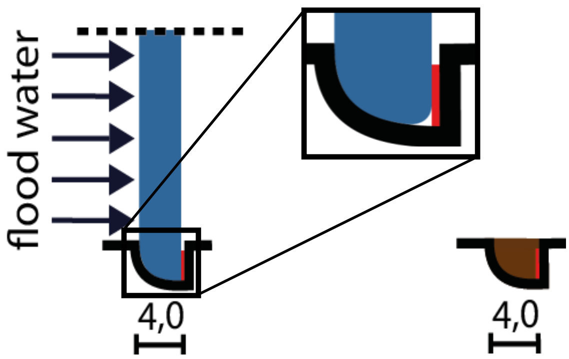


FIGURE 126: DOORWAY BARRIER OPTION 3, SECTION AA

The big advantage of the asymmetrical shaped barrier is the good water tight connection with the concrete floor. If the water from the flood presses against the barrier, the barrier is pushed against the rubber strip (the red line). This pressure from the water will make the connection only more water tight.

Just like in option 2 this alternative is a durable one. The rubber strip is made under floor level, so during dry season the rubber can be protected by a cover. As discussed at option 2, this cover can be made best from wood or plastic.

One side of the barrier is rounded and the other side has a sharp edge. To make sure the barrier can be put in place in an easy way, the sharp edge at the other side is also made rounded. This is shown in the detail in Figure 126. The small rounding at this side cannot be too big, else the connection area with the rubber strip is not big enough anymore.

The big disadvantage of this design is that it is hard to implement in existing buildings. In existing buildings a groove over the whole length of the door needs be made in the concrete. This is a relative expensive operation compared with design option number 1.

Blessing in disguise, the rubber strip is at the flat side of groove. So the flat side of the groove has to make a good connection with the barrier. It is more favourable that the flat side of the groove has to make a good connection with the barrier than if the rounded side should make the water tight connection. Namely it is much easier to make a smooth flat side than a smooth rounded side. If the rounded side is not that smooth, there won't be any problems probably.

Advantage:

+ Very water tight
+ Durable
+ Half rounded edge makes it quite easy to shift through the guiding system (Ease of use)

Disadvantage:

- Hard to implement in existing buildings

To come to the best solution, all options are compared for the four requirements for the design of the floor connection. The four requirements are:

- The connection between the barrier and the floor has to be water tight.
- The barrier has to be durable.
- The barrier must be simple to implement.
- The barrier must be easy to use

All options are judged per requirement and compared with each other. The result of the judgment is in Table 17. Every requirement is judge as follows:

\- = Bad +/- = Medium + = Good

TABLE 17 : MULTI- CITERIA- ANALYSIS OF THE FLOOR CONNECTION OF THE DOOR BARRIER

	Option 1	Option 2	Option 3
Water tightness	+/-	+/-	+
Durability	-	+	+
Simple to implement	+	-	-
Ease of use	+	+	+
Total	**+**	**+**	**++**

In Table 17 are the results of every option added together to come to a total score per option. Option 1 and 2 score only one plus in total and option 3 scores two plusses in total. So from the MCA option 3 is recommended to implement. Option 3 is relative hard to implement, but it is by far the best option during service live. The investment costs are slightly higher, but the benefits probably are also higher, because the option is durable, water tight and easy to use.

GOAL B: PREVENT FLOOD WATER ENTERS THE HOUSE THROUGH THE TOILET

It is good to prevent water from entering the house through the doorway, but this makes only sense if the water cannot enter the house in other ways. So water entering the house through the toilet has to be prevented as well. To reach this goal, three options are designed:

- Option 1: Plug
- Option 2: Pipe
- Option 3: Place
-

All the options should satisfy the next requirements:

1. Water from the toilet has to be stopped until the water outside is 80 cm above the floor level.
2. The toilet should be useable during a flood, otherwise an alternative should be there.
3. The option should be simple to implement, which should give minimum costs. (The simpler to implement the design, the less costs to implement)
4. The option should be easy to use.

The option which scores best on all requirements will be recommended as the best option. All options will be discussed in more detail here. After that all options will be judged by the four requirements.

OPTION 1: PLUG

The first option to prevent water entering a building via the toilet is the simplest option of all. A plug will be placed in the toilet which makes sure the toilet is close and water from the sewer cannot enter the house.

The big advantage of this solution is that it is very simple to apply. Only a good working plug should be designed. The functional requirements for the plug are:

1. Water tight connection between the plug and the toilet
2. The connection must stay closed up to a maximal water level of 80 cm

To make the connection water tight, the whole plug or at least the outside of the plug should be made of rubber. To be sure the connection works by the maximum water level, an external construction should be designed to hold the plug in place. The maximal pressure the plug should resist is equal to a water head of 80cm.

Maybe a better way to resist that pressure is to apply some weight to the plug. If the weight of the plug is equal to the weight of 80cm water, there should be equilibrium between the plug and the water pressure. The plug then will stay in place. This is much easier, so the plug will be made heavier instead of an additional extern construction.

So let's assume there is a weight on the plug and let's also assume this weight is from a steel mass. Steel is relative cheap and has a height mass density, so should be a good working material. If a water head of 80cm should be resist, the height of the steel then can be calculated:

$$m_{80cm\,water} = \rho_{water} \cdot A_{water\,head} \cdot h_{water\,head}$$

$$m_{80cm\,water} = 998 \cdot A_{water\,head} \cdot 0{,}80$$

$$m_{plug} = \rho_{d;steel} \cdot A_{plug} \cdot h_{k;steel}$$

$$m_{plug} = m_{80\,cm\,water}$$

$$7800 \cdot A_{plug} \cdot h_{k;steel} = 998 \cdot A_{water\,head} \cdot 0{,}80$$

Let assume A_{plug} is equal to $A_{water\ head}$. In reality A_{plug} is some larger than $A_{water\ head}$ (D_{plug} is bigger than $D_{water\ head}$ (Figure 129)) but for the calculation this small difference will be ignored. The characteristic height of the steel then will be:

$$h_{k;steel} = 0{,}10\ m$$

To come to the design height, a safety factor is applied. For safety take $\gamma = 1{,}2$

$$h_{d;steel} = \gamma \cdot h_{k;steel}$$

$$h_{d;steel} = 1{,}2 \cdot 0{,}10$$

$$h_{d;steel} = 0{,}12m$$

Assuming $D_{plug} = D_{toilet}$ is around 18cm, the weight of the plug will be:

$$m_{plug} = 7800 \cdot \frac{1}{4} \cdot \pi \cdot 0{,}18^2 \cdot 0{,}12$$

$$m_{plug} = 23{,}8kg$$

The 12 cm steel can be place just above the rubber as shown at the left of Figure 127. With the black handgrip the whole plug can be pulled out and then the toilet can be used again. It is smarter to combine the steel weight with the rubber as shown at the right in Figure 127. Now there is a tapered steel block with a rubber layer at the outside. The rubber layer only has to be around 1cm thick. This design needs less rubber and the plug is far more compact. The less usage of rubber makes the solution cheaper. Again a handgrip is place on the steel to pull the plug out of the toilet.

The weight of 23.8 kg is quite heavy to lift. Therefore, it maybe is better to split the mass in two parts. The first part is shaped like a bucked with a weight of about 12kg has to be placed in the

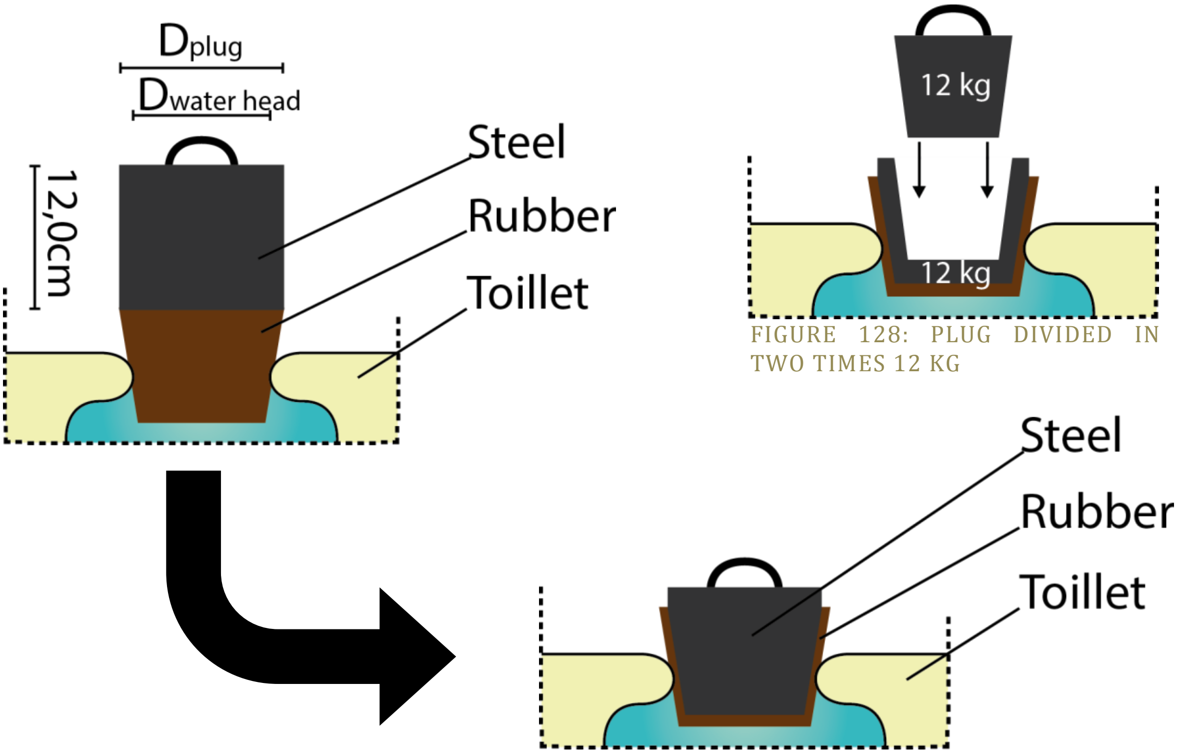


FIGURE 128: PLUG DIVIDED IN TWO TIMES 12 KG

FIGURE 127: PLUG WITH WEIGHT. LEFT: STEEL WEIGHT ON RUBBER PLUG. RIGHT: STEEL WEIGHT WITH RUBBER OUTSIDE

toilet. In the outer part an inner part of about 12 kg can put. This solution is shown in Figure 128. An additional advantage of this design is about the stench form the sewer. The plug makes sure during a flood comes no foul smell from the toilet into the house.

A big disadvantage of is course that the toilet cannot be used any more during a flood. This is quite inconvenient. During a flood there should be an alternative for the toilet. Before option 1 is implemented, a good alternative for the toilet has to be there. An example of an alternative can be something like a chemical toilet. More research should be done to come with a good alternative.

Advantage:

+ Simple to implement
+ No stench from the sewer

Disadvantage:

- Toilet cannot be used any more
- During a flood an alternative for the toilet should be available

OPTION 2: PIPE

In option 2 is tried to design a solution for the disadvantages of the first option, without losing the advantages. The rough design of option 2 is shown in Figure 129. Instead of a plug is a pipe placed on the toilet. The requirements of the pipe are quite similar to the requirements of the plug:

1. The pipe should be minimal 80cm high
2. The connection between the pipe and the toilet must be water tight

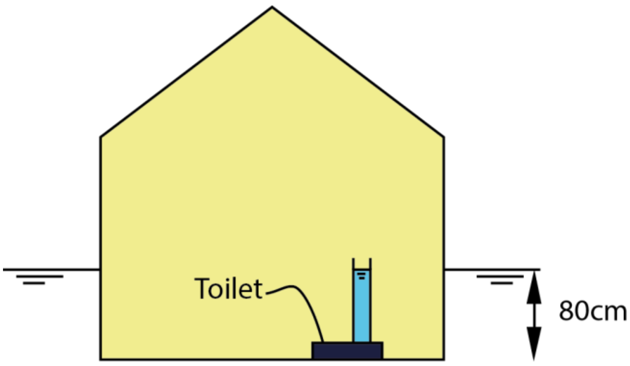


FIGURE 129 : AVOIDING WATER FROM THE TOILET WITH A PIPE

The pipe should be at least as high as the doorway barrier. Assuming that the doorway water barrier is 80 cm, the pipe only has to be 80cm. This follows from the water balance (Figure 129). The doorway barrier only stops the water if the water level is under 80 cm above the floor level. If the water level outside is bigger than 80cm above the foundation, the water will enter the house. It does not make a difference if the dirty water comes from outside or from the toilet. From this point of view it makes no sense if the pipe is higher than 80cm.

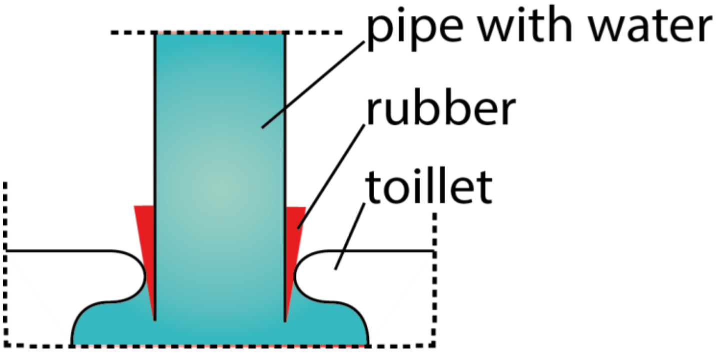


FIGURE 130 : CROSS SECTION OPTION 2

The connection between the pipe and the toilet should be water tight, such that there can be an 80cm high head of water in the pipe.

The big advantage of a pipe above a plug is that the toilet can still be used to put people's excrements in. For example people can defecate in a bucket and emptying the bucket into the sewer via the pipe on the toilet. It bly better than water from the sewer

Another advantage of this option is the simple implementation of the design. The connection between the pipe and the toilet should be water tight, which is the only relative difficult thing. The cross section of a possible design of this option is shown in Figure 130. The design is quite simple; a pipe with a rubber strip at the end. The rubber strip has a tapering shape, such that it can be clamped in the toilet easily. The rubber part makes sure the connection is water tight. In the design are no measures taken for horizontal forces in the pipe for example caused by the eccentricity of the pipe. A more detailed design and calculation should be done to determine if horizontal supports are needed.

Advantage:

+ Simple to implement
+ Toilet can still be used as drain

Disadvantage:

- Stench from the sewer

OPTION 3: PLACE

The third option is the most practical option during a flood but also the most radical solution to implement. In the third option there is nothing designed, but the place of the toilet is changed. From the water balance it is logical to place the toilet on a higher place. As long as the toilet is placed higher than the water level outside is, water will not enter the house through the toilet. So it should be a quite practical option to place the toilet on the second floor instead of the first floor.

There are two disadvantages for this option:

- This option can only be applied in buildings with two or more floors
- It is quite radical and expansive to place the toilet from the first to the second floor in existing buildings

From these two disadvantages can be recommended that option 3 is probably only benefits to apply in new buildings with two or more floors. New buildings can be designed in such a way that the toilet is placed at the second floor or higher.

Advantage:

+ Toilet can be used during a flood
+ Water will not enter the house via the toilet

Disadvantage:

- This option can only be applied in houses with two or more floors
- Quite radical and expensive solution in existing buildings

RECOMMENDATION

To come to the best solution, all options are compared for the four requirements for the design of the floor connection. The four requirements are:

- Water from the toilet has to be stopped until the water outside is 80 cm above the floor level
- The toilet should be useable during a flood, otherwise an alternative should be available.
- The option should be simple to implement.
- The option should be easy to use

All options are judged per requirement and compared with each other. The result of the judgment is shown in Table 18. The first requirement 'stop water' should be satisfied by every option. Only the options which satisfy this requirement are usable. Therefore, this requirement is judge by YES or NO. If the 'stop water'-requirement is not satisfied, the option is useless and won't be applied. The other requirements are judged as:

- = Bad +/- = Medium + = Good

TABLE 18: MULTI-CRITERIA-ANALYSIS FOR OPTIONS TO PREVENT WATER ENTERS THE HOUSE VIA THE TOILET

	Option 1	Option 2	Option 3
Stop water	YES	YES	YES
Useable toilet during flood	-	+/-	+
Simple to implement	+	+	-
Easy to use	+	+/-	+
Total	**+**	**+**	**+**

In Table 18 are the scores for every criteria added together per option to come to a total score per option. All options can stop the water from the toilet and all options score one plus in total. Above it is already explained that option 3 can best be applied in new houses, because this option is very hard to implement in existing houses.
The big disadvantage of option 1 compared with option 2, is that the toilet cannot be used during a flood. If there is a good and cheap alternative for the toilet, option 1 should be the best. It is recommended to do some more research for an alternative toilet so option 1 can be implemented. If there is no alternative for the toilet during the flood option 2 is recommended.

GOAL C: PREVENT FLOOD WATER FROM REACHING THE POWER POINTS

To prevent the power points from flood water, two alternatives are possible:

- Power point placed higher
- Removable power points

The first alternative is the simplest one. The power points should be placed as high as possible to prevent damage from the flood water. They should not be placed too high for practical reasons. For example if the power point is placed two meters above floor level, almost nobody can use them without standing on a chair or something. So an optimum should be found between the damage of the power point and the practical usage of it. This optimum probably lies around 1,60m. This is already 30cm higher than they are now, but everybody can still use it. Further research should be done to come to a real optimum.

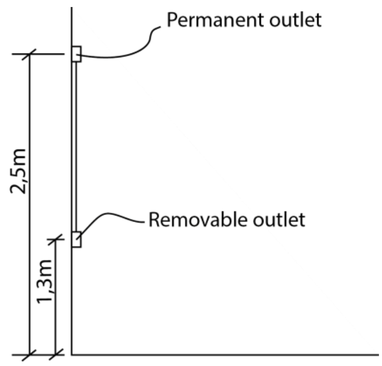


FIGURE 131: PERMANENT OUTLET WITH EXTENSION PIECE TO REMOVABLE POWER POINT

Another option is not an optimum but an alternative with extension piece. Now the permanent outlet can be placed as high as possible, let say 2.5m above floor level. The extension piece with a removable power point then can be placed between the height placed power point and the practical height for usage the power point, Figure 131. During the dry season the power point is on a very practical height, for example the 1.3m above floor level. This height is also been observed during the fieldwork. During a flood the extension piece with the removable power point has to be removed, so they will only be damaged if the water level is higher than 2.5m above the floor level.

4. CONCLUSION AND RECOMMENDATIONS

The Thua Thien-Hue province suffers from different water related problems which together are the cause of a large loss of income, wealth and even human lives. During the wet season the province suffers from severe floods which are caused by the combination of large river discharges, heavy rainfall and high tides. During the dry season the opposite is the case. A combination of drought and salt intrusion from the sea causes problems for both the agriculture and navigation of the river. The water causes a damage worth approximately 1,5% of the GDP of the province every year, which is considered unacceptable.

First of all a thorough research has been performed to get a good insight into the cause of the problems. This is followed up by a brainstorm session about possible solutions which are either focussed on getting rid of the cause of the problems, or to minimize the damage if disasters occur. This brainstorm session has resulted in a set of 8 possible solutions which have been tested by a multi criteria analysis. The criteria which are used are based on both the requirements from the stakeholders and the functions of the water. The MCA brought the amount of options back to two, which are elaborated further.

During the more detailed design, the effectiveness of both the solutions has been investigated with help of SOBEK. Besides, a cost/benefit analysis is performed in order to check for the profitability of both the solutions. This has led to the recommendation for the solution "Lake Hue".

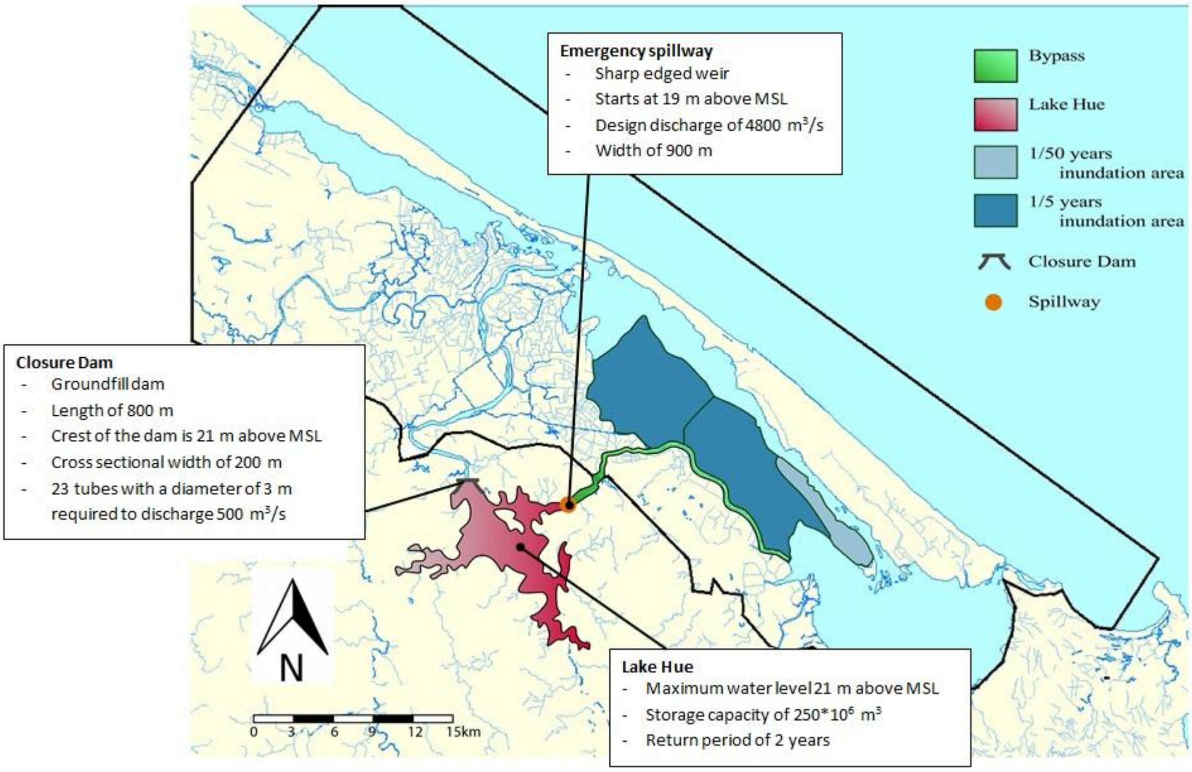


FIGURE 132: THE RECOMMENDED SOLUTION CONSISTING OF A RETENTION AREA UPSTREAM OF THE CITY OF HUE CALLED "LAKE HUE"

The recommended solution consists of the construction of a water retention area upstream of the city of Hue, which can be used to regulate the discharge of the Huong River, see Figure 132. Lake Hue makes use of the principle of peak shaving: during the high discharges which exceed the capacity of the Huong River, most of the discharge will be retained to prevent flooding of the province. The water will be released afterwards over a larger period in such a way that the capacity of the Huong River will be sufficient to cope with the water. The volume of the retention area is based on design conditions for a one in five years event. The total volume of the reservoir should at least be 250 million cubic meters, which comes down to a maximum water level of 19 meters above mean sea level. For the sake of resiliency, an emergency spillway is recommended to steer the water away from the city as soon as the danger of overtopping of the entire dam is present.

The water retention area appears to be very effective: the whole city of Hue, which is the most vulnerable area to flooding, remains dry during a one in five years event. In Figure 133 is the flood map of a one in five years event compared with the map of the desired return periods. The flood map comes from the SOBEK model. The figure shows that the center of Hue stays dry and that only a small part of the 1/100 area at the east side of the Huong River will be flooded. Also the most 1/50 areas stays dry during the one in five years event, which is quite good. The yearly reduction of damage is estimated to be nearly 80%. This reduction is based on the combination of land use maps, flood maps and a model which relates the inundated areas to the damage of the flood.

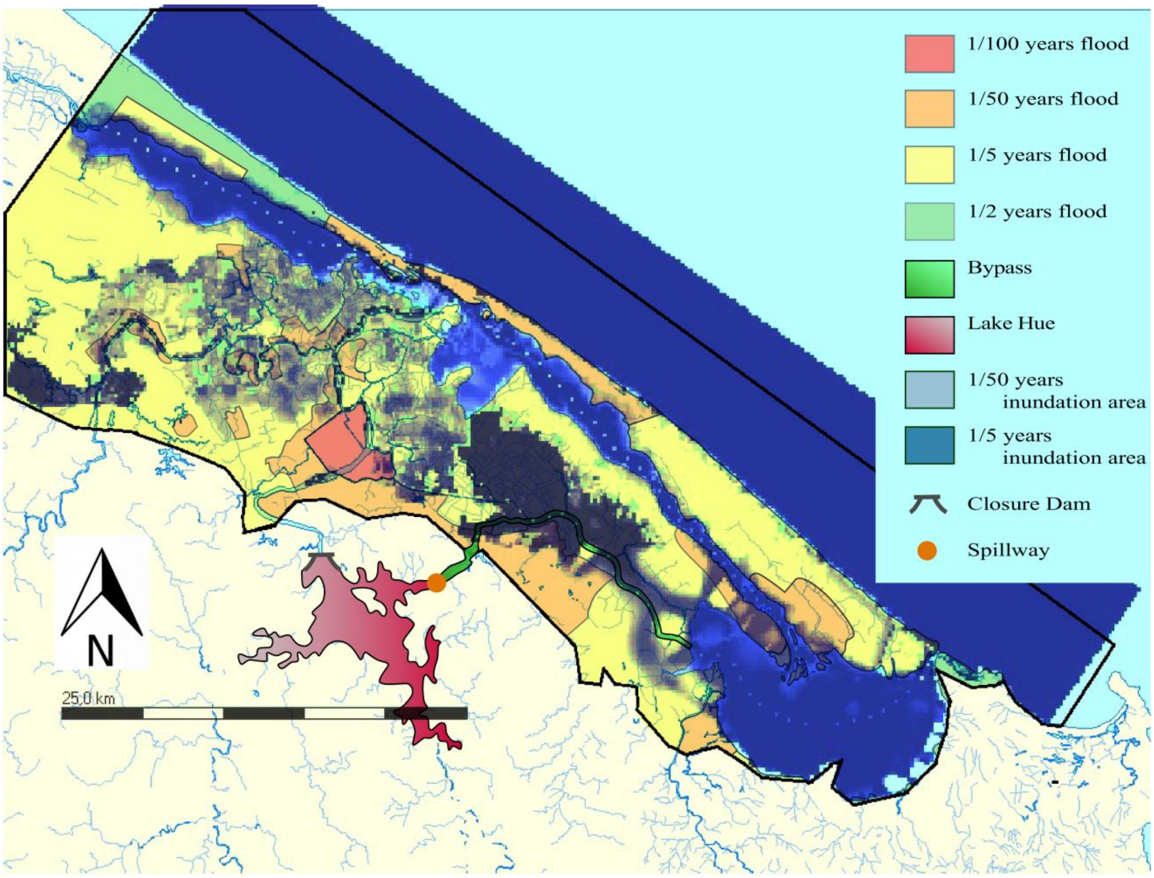


FIGURE 133: ONE IN FIVE YEARS EVENT COMPARED WITH DESIRED RETURN PERIODS

To make the solution operational, a large earthfill dam has to be constructed in the northwest of the area to retain the water when needed. The length of this dam will be around 800 meter while the width of the base needs to be in the order of 180 meters for the dam to be stable. The bottom profile, and also the depth of the dam, varies over the length of the dam. The height of the dam will be approximately 29 meters at the deepest point of the cross section which has to be closed. A total volume of around 893.000 cubic meters of ground needs to be placed to construct the dam. The other boundaries of the water retention area will consist of the natural slopes of the mountains surrounding the area.

The dam will be equipped with multiple pipes and valves to control the discharge flowing through the dam. Around 20 pipes with a diameter of 3 meters need to be placed at a height of 20 meters below the crest of the dam. The valves should be operated in such a way that regardless the water level, the discharge through the dam will constantly be 500 cubic meters per second during peak conditions. This discharge is equal to the capacity of the Huong River downstream.

Also, an emergency spillway has to be created to direct the water directly to the lagoon in case the retention area does not have enough capacity to retain the water during extreme events. In this way a less valuable area of land will be sacrificed in order to protect the city of Hue. The route from the emergency spillway to the lagoon has to be bounded by dikes to keep the water flowing in the right direction and to prevent flooding of vulnerable areas. This spillway is designed for once in 100 years conditions and should therefore be able to discharge an amount of 4800 cubic meters per second. The spillway can best be constructed as a sharp crested weir. To be able to discharge the right amount of water, a total width of about 900 meters is required.

The costs which are involved to build the structures are based on reference projects from the neighbourhood, which are construction of the “Ta Trach” and “Ho Thu Dien” reservoirs. The total costs of the proposed solution are estimated to be 150 million euros.

This seems to be a large amount of money but on the long term however, these measures appear to pay off. According to the costs benefit analysis, the payback time for the retention area is in the order of 15 years if a discount rate of 2% is assumed. The net present value of the summation of investment costs, damage of floods and maintenance costs are almost half of the costs in the reference scenario in the next coming 50 years.

By making such a reservoir, not only the safety will improve, but also the willing to invest by a company in the economy in the province. This will give the economical situation in the province a big boost, which will lead to more welfare.

The current political situation in Vietnam however makes it hard to apply such large changes to the system. Governmental organizations of many different levels have to agree on changes of the system which makes the recommended solutions difficult to implement.

Some following up studies for the Thua Thien-Hue are given below:

RESEARCHING THE DISCHARGE CHARACTERISTICS OF THE HUONG AND BO RIVER

SOBEK has been used in this study to estimate the maximum discharge that can safely flow through the Huong River. This discharged was then used to calculate the dimensions of the new reservoir. Knowing the real discharge just before flooding will occur is vital in designing this option further. For even more improvements in the area, this information on the Bo River would be just as useful.

INVESTIGATE THE IMPACT OF AN ADDITIONAL INLET IN THE LAGOON

In some cases during a flood the water inside the lagoon cannot be discharged quickly enough. This will result in flooding inland, due to the backwater curve. To enlarge the outflow discharge of the lagoon an additional inlet can be made, but a research must be done on the impact of the salinity in the lagoon, the environment and the coastal morphology.

IMPROVING THE SOBEK MODEL

The flooding modelled in this study gives an indication of the flood extents but is far from accurate. A new model, with a higher resolution elevation data, updated cross sections and structures will allow for more accurate modelling. This study might be combined with collecting better meteorological input data. Currently, the modelled flooding matches the water levels in the Huong River during a once in five year situation, but does not use the actual data from that such an event. Having such a model would make is much more credible.

USING CLIMATE CHANGE SCENARIOS TO ESTIMATES FLOODING IN THE FUTURE

Climate change is not taken into account in this study. But it is a significant part of minimalizing flood damage in the future. Estimating the rainfall, runoff and sea level rise under the different scenarios made by the international climate change comity and modelling the resulting flood is very important.

URBAN DRAINAGE IN HUE

There is a sewerage network in Hue, but it does not cover all the populated areas and needs renovating. A new study can review the current state of the system in detail, by using remote controlled video equipment. Using this data, a new plan can be made to optimize the urban drainage and water quality.

COMPARISON OF THE RETURN PERIODS OF RAINFALL, RIVER WATER LEVELS AND FLOOD DAMAGE

Return periods are a way of indicating the chance on the occurrence of an event. This study has given return periods to different areas indicating what the chance of flooding ought to be. Water level data from the Kim Long measuring station was used with their return periods. The rainfall data that caused these water levels were then used to calculate water volumes. The return periods of the rainfall events do not necessarily be the same as that of the water level, let alone the flooding that result from it. Analyzing the return periods of rainfall, water levels and the resulting flooding alone will allow for a better understanding of how flooding can be decreased further.

HYDRAULIC STRUCTURES

The hydraulic structures needed to implement the second scenario are only roughly elaborated. Global dimensions of the dam and tubes which pass water through the dam are known but a detailed study has to be performed on the reservoir and the dam itself before it can be constructed.

Data of soil conditions around the position of the dam were at the moment of the project unavailable. In a follow up research, the soil at the location around the dam has to be investigated on permeability to prevent ground water flow around and below the dam which can cause instability due to possible landslides. Also the soil has to be examined on stability to prevent unequal subsidence of soil.

Apart from the existing soil at the location also a study has to be done on the soil which will be used for constructing of the dam. In this project the assumption is made that the whole dam consists of a uniform clay layer with standard parameters for internal friction and cohesion. In a follow up researches a more detailed plan for the dam has to be elaborated which also consist of a part that threatens the cover protection of the dam against rainfall and storm conditions.

During the dimensioning of the tubes in the dam only rough dimensions and quantities are used. An advanced design has to be made in order to determine the detailed dimensions and parameters of the tubes itself and the valves installed in it. Some tubes must be closed off during high water levels in order to prevent a too big flow through the tubes. Also the elevation levels of the different elements have to be elaborated. Know only some rough estimations are made for the location of the top and bottom of the dam.

5. REFLECTION

After eight weeks of project, the first steps towards a water management plan have been taken with this document as a result. Six Dutch students have been experiencing the life and procedures in Vietnam, without any prior knowledge on the Vietnamese government policies, habits and language. This makes it very important to put the project and this resulting document in the right perspective.

Eight weeks is a very short timeframe to get accustomed to the Vietnamese habits, the project area of the Thua Thien-Hue province, the Vietnamese regulations and obtain all available information without Vietnamese linguistic skills. This means that numerous significant assumptions have been taken in order to come to a useful conclusion within the appointed time restraint.

5.1 PROJECT RESTRICTION

When considering the results of this project, it is important to keep the restrictions of such a project in mind. First of all, the group consists of six students in the field of Civil Engineering, which means that none of the project members has any professional experience in a project like this. Also, a group of six persons is rather small in order to evaluate the water management system of an entire province. Secondly, the data used had to be partly improvised in order to cope with incomplete provided data and the inability to find better data due to language and time restraints. This language problem also made it partly unable to access Vietnamese information about flood and governmental policies.

This data has been used in a SOBEK model, which has been provided to us. Because of the short project time, there was no time to make and calibrate this model ourselves. This means that the model may be less useful to us as it has not been made with the same goal in mind as our project. In this particular case, the model has not been made to model different severities of floods and has not been calibrated on different levels of floods.

Lastly, no local inhabitants have been consulted for local information. The week of fieldwork has mainly been used to visit the areas around the city of Hue. Especially those areas where little was known of, or areas that would possibly be used for improvements of the system. Together with the language problem, this meant that no inhabitants have been heard about their situation, their thoughts about the floods and possible improvements to their situation. Also, their willingness to relocate is unknown.

5.2 VALUE OF THE CONCLUSION

Taking the project restrictions in consideration, large caution is needed when addressing the conclusion of this document. It should not be seen as the final and only solution to the many problems faced by the Thua Thien-Hue province. It shows the most promising of solutions, based upon the knowledge and considerations mentioned in the project document. Although we know that this knowledge about the area and the problems are far from complete, some applicable improvements have been discussed.

In the report also no climate change scenarios are investigated. This could also influence the dimensions of the structures.

If a change in one of the concerning fields would lead to a change in the arguments on which the current choice is based, this could lead to another combination of improvements being more favourable.

It is certain that there are numerous improvements to be made to the current chosen and designed improvements, due to extra information becoming available. The recommendations show the fields on which we think the largest improvements can be made when it comes to adding information.

In conclusion, although we know that the project is far for complete, we hope that we could provide a fresh and creative view on the immensely complex problems faced by the Thua Thien-Hue province and its inhabitants.

A project management plan is attached in the report in Appendix A. This report is made to ensure the quality during the project.

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7. APPENDICES

APPENDIX A: PROJECT MANAGEMENT PLAN

In order to ensure the quality of the project, a management plan has been set up. This document includes the way in which responsibilities are assigned, the used methods for communication, the group profile, the task division and the concurrent engineering. This document ensures that miscommunications, double documents and mistakes in the design will be reduced to a minimum. Besides, it will help to share the information in such a way that every member of the project team still has an overview of the whole project.

COMMUNICATION & RESPONSIBILITY ASSIGNMENT

All of the group members will work in the same room. This makes it easier to communicate and check up on each other's work. However, this does not guarantee a smooth development of the project. This is the reason why some agreements have been made on the communication between the members of the group.

First of all, a group discussion is organized to decide about the outline of the project. This outline includes both the work plan and the subjects which will be investigated in the next stages of the project, but also touches upon the things which will not be investigated during the project.

As soon as the global contents of the report are known, a work file is set up in Microsoft Excel to distribute the tasks over the different team members. This file includes the author of each of the paragraphs, the one who checks the work of the author for the first time and the final editor. This file clarifies the responsible ones for each part of the report. This is essential to control the quality of the work: as long as someone can be held responsible for a certain part of the report, remarks on certain parts can be addressed to the right members.

This excel sheet will be updated on daily basis to keep track of the progress and to make sure that everything is still going according to the schedule.

A screenshot of this file is shown in Figure 134 (taken on December 28th):

Paragraaf	Gedaan	Door wie / Eindverantwoordelij	Deadline	Opmerkingen
Introduction to the Thua Thien-Hue province				
the Framework of Integrated Water Manangement				
Upgrading the flood defence system of Hue				
c. Applying the Framework of Integrated Water Management to the Thua Thien-Hue province		Tim Hessels	18-dec	
i. Desired return periods		Arjen	18-dec	
ii. Required water defence system		Erik, Tim van Corven	18-dec	
iii. Prevention against flooding and drought		Dennis	18-dec	
d. Discussion		Tim Hessels		
3. In-depth analysis			2-jan	Redactiestuk
Assessing the effectiveness			2-jan	Redactiestuk
i. Combination 1 - By-pass		Tim van Corven	24-dec	
ii. Combination 2 - Retention area		Tim Hessels	30-dec	
iii. Modeling the combinations with SOBEK		Dennis	24-dec	
Preliminary Design - Combination 2			2-jan	Redactiestuk
i. Structural aspects		Tim van Corven	30-dec	
ii. Structural dimensions		Tim van Corven	30-dec	
iii. Cost-benefit analysis		Arjen	30-dec	
Huups constructiehoekje		Jeroen	30-dec	
Consequences of the scenarios on other hydrological functions		Dennis	30-dec	Ter controle

FIGURE 134: WORK FILE

Furthermore, every day will start with a short discussion about the activities of each member for the day. This is done to be able to coordinate the tasks and to make sure that everyone is doing an activity which is useful for the project. Besides, it makes sure that everyone still has an overview of the whole project and knows his part in it. This will improve the quality of the output of the members and reduces the final editing which has to be done.

GROUP PROFILE

In order to distribute the tasks over the group members as good as possible, it is important to get an idea of the background and specialisms of each member. The group consists of members with knowledge about different topics and different specializations. Research on this has resulted in the following group profile:

Jeroen van Oosten: Master student in Structural Engineering. Specialized in concrete structures and structural mechanics. Has experience in working with Adobe Illustrator CC, Microsoft Excel, Midas FX+ for Diana and TNO Diana.

Dennis Kuijk: Master student in Water Management. Specialized in water resources management. Has experience in working with GIS software, MATLAB, Microsoft Excel and SOBEK.

Tim Hessels: Master student in Water Management. Specialized in water resources management and hydrology. Is good at guarding the quality of reports. Has experience in working with GIS software, MATLAB, Microsoft Excel and SOBEK.

Tim van Corven: Master student In Hydraulic Engineering. Specialized in hydraulic structures and has some knowledge about port design. Is good at the visual editing of reports. Has experience in working with Excel and SOBEK.

Erik van Berchum: Master student In Hydraulic Engineering. Specialized in Hydraulic structures. Has finished a leadership track at Stanford University. Has an excellent knowledge on the English language and is good at creating the outlines of a project. Has experience in working with Microsoft Excel, Adobe Illustrator CC and MATLAB.

Arjen Zorgdrager: Master student In Hydraulic Engineering. Specialized in Hydraulic structures. Has some knowledge about coastal dynamics and river dynamics and is interested in economics Has experience in working with Microsoft Excel and SOBEK 1D.

DIVISION OF LABOUR

Now that the tasks to be done and the specialisms of the group members are known, it is possible to distribute the tasks over the group members. The tasks are addressed to the members based on their expertise and knowledge. In general one can say that the water management students are held responsible for the modelling of the floods while the hydraulic engineering students are responsible for the design of the control structures. The single structural engineering student is responsible for the recommended adjustments to houses in the region.
The specific tasks of each of the members are depicted below:

Jeroen van Oosten: Creation of different maps with help of Adobe Illustrator CC. Is also responsible for creating a masterplan to make the houses located in the flood prone areas of the Thua Tien Hue province flood proof for as little money as possible.

Dennis Kuijk: Modelling of the floods in SOBEK and performing sensitivity analyses for the different parameters. Is also responsible for the design of the emergency spillway of the reservoir.

Tim Hessels: Assembling the files which are handed in by the other members and final editing of the report. Is also responsible for the calculation on the required dimensions of the reservoir.

Tim van Corven: Design of the different structures which are needed in order to reduce the damage caused by floods in the Thua Thien Hue province.

Erik van Berchum: Creating the working schemes and outline of the project. Is also responsible for the final check of the grammar and syntax of the whole report.

Arjen Zorgdrager: Performing a cost-benefit analysis on the recommended water defence system. Is also partly responsible for the design of the control structures of the reservoir.

CONCURRENT ENGINEERING

There is quite some overlap between the tasks performed by different members of the group while the short time which is reserved for the project requires parallelization of the working schemes. In order to prevent miscommunications, it is of great importance to detect the overlaps between the tasks of different group members and to make agreements on the boundary conditions between them. This makes it possible to work on a certain subject individually while misunderstandings between the different members are prevented.

During the research, the following three overlaps were identified:

WATER MANAGEMENT VERSUS HYDRAULIC ENGINEERING

The boundary conditions which are required to design the hydraulic structures should be extracted from the research performed by the water management group. This makes coordination of the work of the different groups essential. At first, the cause of the water related problems should be identified by a research which will be performed by both the water management- and the hydraulic engineering students. As soon as the causes are known, the hydraulic engineers will try to find concepts to cope with the problems while the water management students will set up a SOBEK model for the area. When these tasks are finished, the effectiveness of the proposed measures of the hydraulic engineers can be tested by making adjustments to the SOBEK model.

WATER MANAGEMENT VERSUS ECONOMICS

The costs of the floods are closely related to the area and depth of inundation during a flood. The economical part will focus on the research on the relation between land use, inundated areas and inundation depths while the water management students will fine-tune the SOBEK model to get flood maps which are as close to reality as possible. By combining the work of both disciplines, it is possible to get an estimate for the total costs of floods for a certain reference period. Besides, as soon as the effectiveness of the proposed structures is known, the benefits of the flood reduction can be expressed in terms of money by combination of the adjusted flood maps and the economic model.

HYDRAULIC ENGINEERING VERSUS ECONOMICS

As soon as the proposed structures to control the water are known, one can start with an estimation of the costs of the measures. The hydraulic engineering students should be clear about the amount and global dimensions of the structures. As soon as this is done, information should be found about unity prices of the measures and costs of reference projects. The cost analysis should be used as a tool for the hydraulic engineers to decide which option suits the best.

APPENDIX B: FIELDTRIP

In the following appendix, first the blind spots before the fieldtrip are given. After that a day by day summary of the fieldtrip in the framework integrated water management of the Thua Thien–Hue Province is given. The fieldtrip took six days. In the last part of this appendix the findings of the fieldwork are summed.

BLIND SPOTS IN THUE THIEN-HUE PROVINCE

Before the field trip, limited data was available on the land use and water defence systems of several parts of the project area. The missing data was gathered during a tour by car across the project area, a bike ride through the area and interviews with the local dike department and the meteorological centre of Hue.

The first blind spot was the area in the north-west, just south of the lagoon. Satellite images of this area were too unclear to come to a well-funded conclusion. During the field trip by car, it turned out that this area consist of sand dunes, graveyards, bumpy roads and some cattle. The land was a bit elevated which makes it less vulnerable to floodings.

The second blind spot was the area between the sand dunes and the city of Hue. According to the available maps, this area should consist of plantations, some villages and regular agriculture. In practice, there were visually no differences between the plantations and other agriculture. The area had a very low population density and bad infrastructural facilities which all together makes it a rather invaluable area.

The land use in the strip north of the lagoon was not clear either. The site visit made clear that the part just west of the Thuan An inlet is very densely populated. Approximately 15 kilometres more to the east, the population density decreases to almost nothing. Even more to the east there are some small villages which are more densely populated.

The next unknown part was the area east of the centre of Hue. This area was visited by bike and turned out to be inundated at present. There are no crops present at all during the wet season since this area is flooded every year. During the dry season, this area consists of rice fields.

The last subject that had to be investigated was the current state of the water defence system. In order to investigate this, bikes were rented to cycle along the river banks. There were hardly any dikes constructed along the river. Only at some places bank protection was constructed in order to prevent further erosion of it, especially in the outer bends of the perfume river. The area around the lagoon has been investigated by car. Besides, an interview with the local dike department made clear that the dikes around the lagoon are still under construction.

TRIP AND INTERVIEWS

SUNDAY 1 DECEMBER

After a tiring train journey of 13 hours from Hanoi to the city of Hue the project team arrived at Sunday 1 December in the city of Hue. For today a meeting with Ms. Le Thi Hanh was arranged. This woman who also lives in Hue works at the Department of Environment and Natural Resources in Hue and could provide a lot of information to the project team.

FIGURE 135: DURING THE FIELDWORK BICYCLES WERE USED TO GET A BETTER INSIGHT OF THE DIRECTLY SURROUNDING OF THE CITY OF HUE

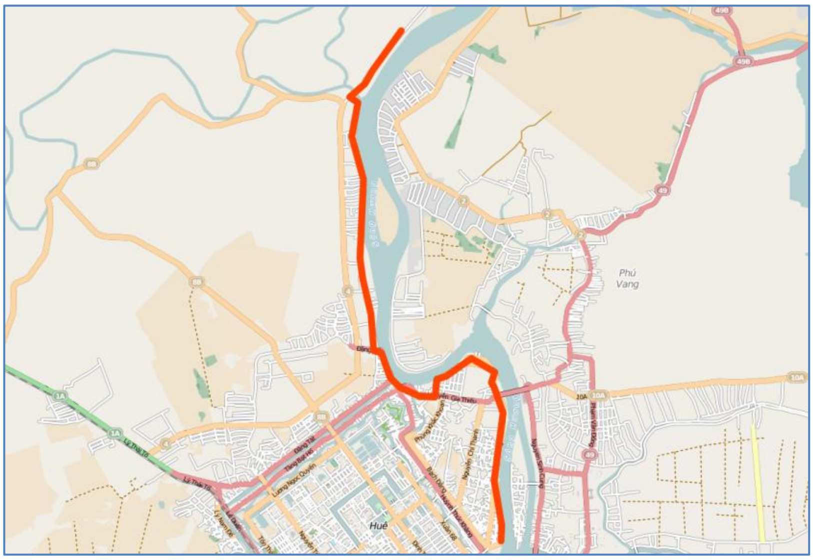


FIGURE 136: OVERVIEW OF THE ROUTE TAKEN ON THE SECOND DAY OF THE FIELDTRIP

FIGURE 137: HOUSES AND OTHER BUILDINGS IN DIRECT VICINITY OF THE RIVER

After the team has introduced the project, Ms. Hanh gave some information and answers to the asked questions of the project group. She also provides some documents and information about the area and makes an appointment at the Hydrological Centre in order to obtain rainfall data for the 1999- and other floods.

MONDAY 2 DECEMBER

To get better insights of the directly surrounding of the city of Hue, this day was used to do some sightseeing by bicycle, see Figure 135. The tour started in the centre of Hue and went up to the north at the downstream side of the Huong River. A lot of riverbanks have been viewed and also a lot of pictures are made for possible use later in the report. A summarize of interesting and important points are given and an overview of the route taken can be seen in Figure 136.

In Figure 137 can be seen that there are houses in direct vicinity of the river. There is no space for possible flood protection measures like for example dikes or quay walls. This situation is not only for the point specified but common for large areas along the perfume river. No place for such protection structures are possible along the whole route that we have bicycled. This was also a very dense populated area. The houses were built very close to each other.

On some places along the river there are erosion protecting measures taken. In case of Figure 138 gabions and a layer of geo-textile behind are placed to prevent erosion to the riverbank. A graveyard was located behind

FIGURE 138: EROSION PROTECTION BY GABIONS ALONG THE HUONG RIVER

FIGURE 139: EROSION SPOT AT THE ABUTMENT OF A BRIDGE

those gabions.

During the fieldtrip marks of floods are visible along some parts of the area. In Figure 139 can be seen that on an abutment an erosions spot was created in all probability during previous floods.

TUESDAY 3 DECEMBER

The exploration of the day before was continued with another bicycle tour through the area under the direction of a guide, who lives in this area his whole live and had also experience the 1999 flood. On this day the area east of Hue was visited. During the tour the guide had showed some flood marks and tells from own experience about water levels during the 1999 flood. A map with the route taken is showed in Figure 140.
The route leads to areas used for agriculture. During the trip some irrigation channels were visible, see Figure 141.
At the point of Figure 143 the guide showed that the water level during the 1999 flood was higher than the top of the bridge on the left side of the picture. During the moment of the fieldtrip the water level was approximately 4 meters lower than the top of the bridge.

In Figure 142 the road TL4 crosses a part of the land that was still flooded, in the summer this area is used for agricultural purposes. In this area there were also some fishery activities. According to the guide this land is flooded most of the times.

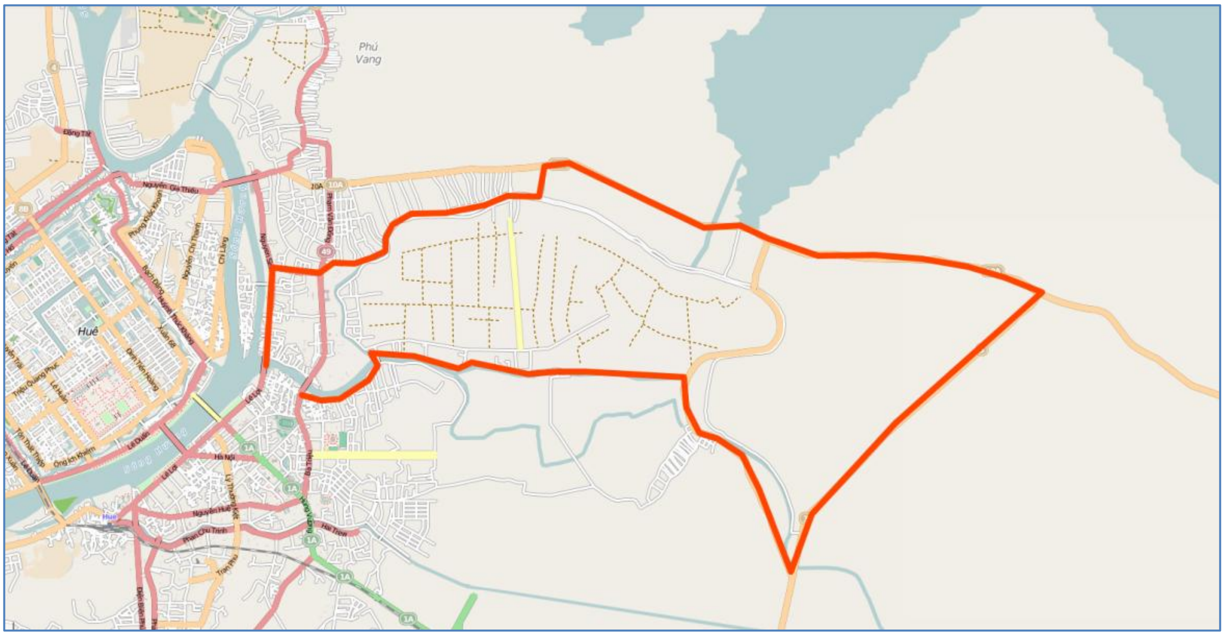


FIGURE 140: OVERVIEW OF THE ROUTE ON THE THIRD DAY OF THE FIELDTRIP

The guide knew also a place where flood markers were located. In Figure 144 a concrete rod is visible where in times of flood the water height can be measured.

FIGURE 143: ONE OF THE PLACES WHERE THE GUIDE TOLD ABOUT HIS OWN EXPERIENCE OF THE 1999 FLOOD

FIGURE 141: IRRIGATION CHANNEL

FIGURE 142: AREA THAT IS STILL FLOODED, IN THE SUMMER THESE ARE AGRICULTURAL FIELDS

WEDNESDAY 4 DECEMBER

Because the project area is too large to visit al places by foot or bike a car including a driver was rented to visit the distant places. This day was used to visit some spots lying to the south-east of Hue.

The route we conceived, which is shown in Figure 145, took us to a weir which can be seen in Figure 146. At the moment of the fieldtrip the height of the weir was above the water level. There was also some erosion visible at the riverbanks near the weir. This can be seen in Figure 147.

FIGURE 144: CONCRETE ROD TO READ THE WATER LEVEL IN TIMES OF FLOOD

After visiting the weir, the route was going to the Thuan An inlet north of Hue and at the end of the Huong River. Afterwards the route took to the Tu Hien inlet more lying to the south. A picture of a bridge which is crossing the Tu Hien inlet can be found in Figure 149.

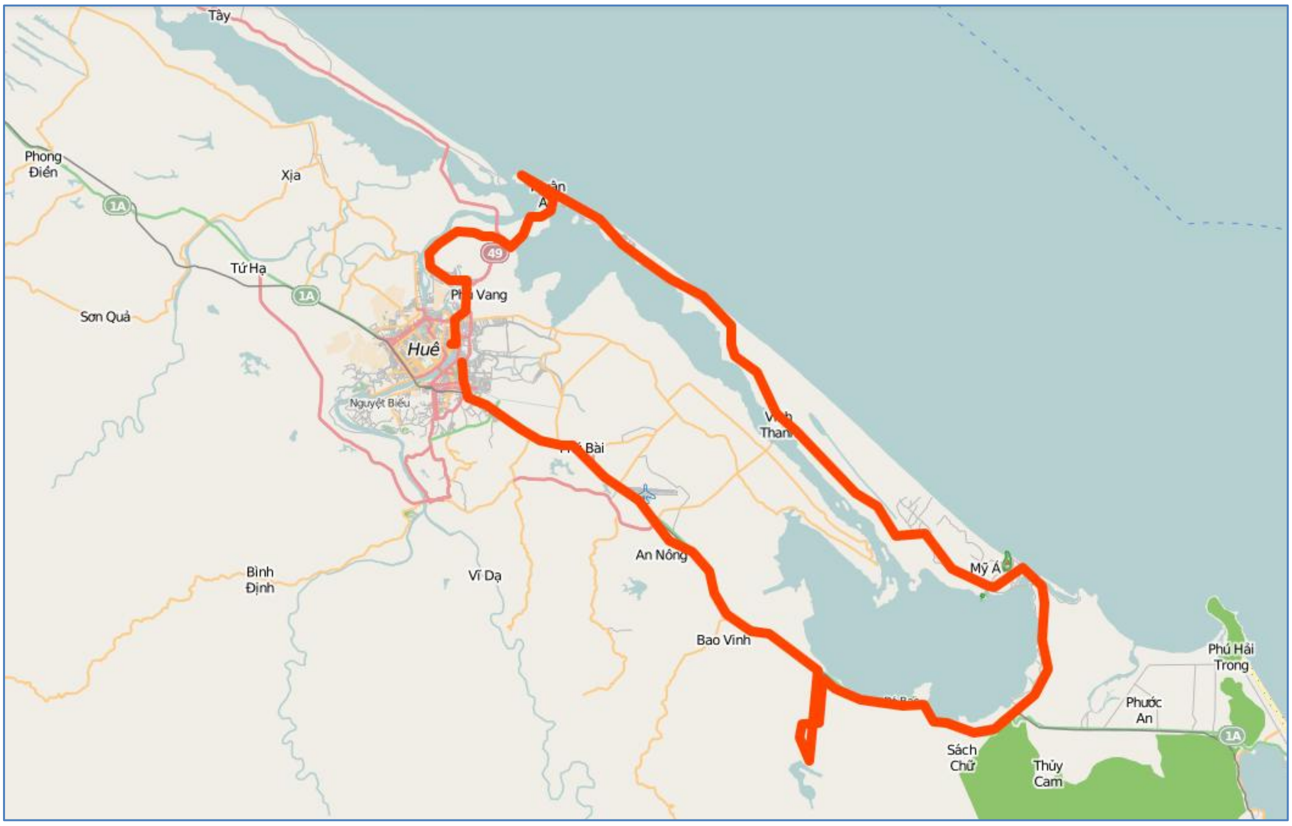


FIGURE 145: OVERVIEW OF THE ROUTE ON THE FOURTH DAY

FIGURE 146: A WEIR LOCATED ALONG ONE OF THE TRIBUTARIE OF THE HUONG RIVER

FIGURE 147: EROSION NEAR THE WEIR

After visiting both inlets, the Truoi reservoir was on the program. See also Figure 148 and Figure 150.

THURSDAY 5 DECEMBER

Also this day a car was hired and we as project group went to the north-west of the project area. Goals of this day were to see the riverbanks of the different rivers, see their protection measures if available and see the weir in the vicinity of Hương Phong. The route can be seen in Figure 151. Some pictures of the riverbanks can be seen in Figure 154 and Figure 153

After seeing a lot of riverbanks we visited a weir in the vicinity of Hương Phong. The weir was constructed under the bridge. At the moment of visiting the weir was open. The function of the weir is to minimize the salt intrusion into the Huong River by closing the weir when this rivers discharge is low. See also Figure 152.

FIGURE 149: BRIDGE OVER THE TU HIEN INLET

FIGURE 148: TRUOI RESERVOIR

FIGURE 150: A SPILLWAY OF THE TRUOI RESERVOIR

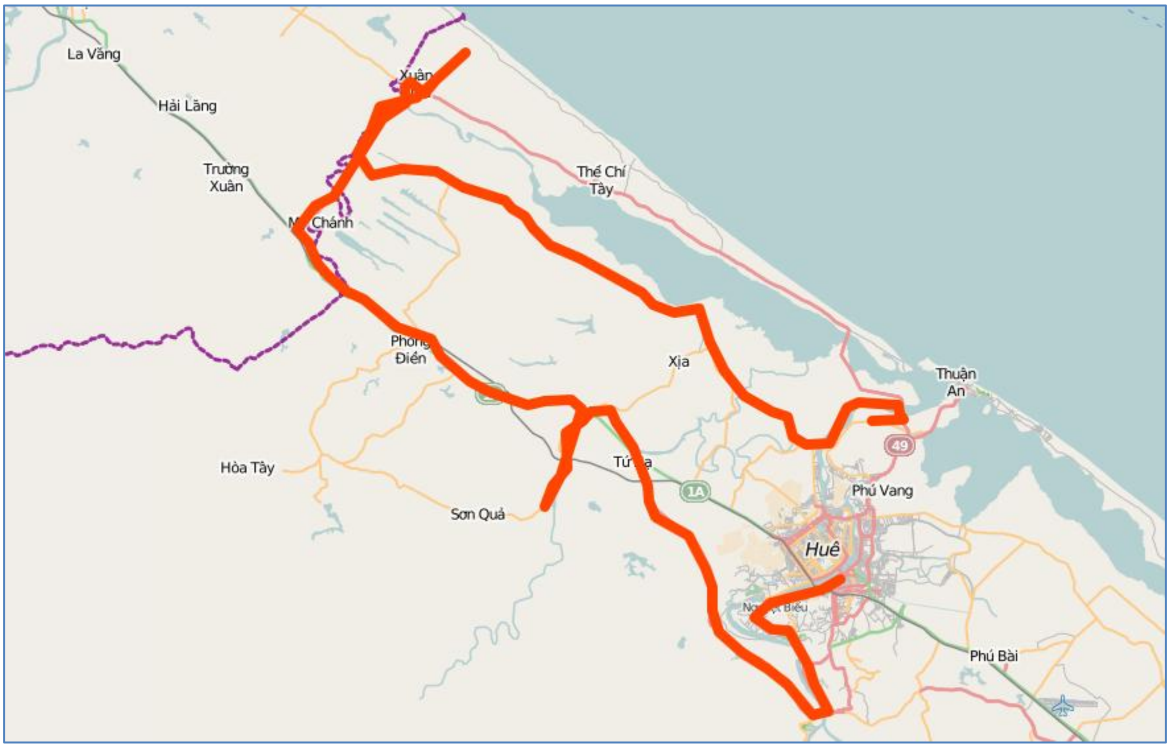


FIGURE 151: ROUTE OF THE FIFTH DAY

FRIDAY 6 DECEMBER

On this last day of the field trip two meetings where scheduled. There was an appointment made with the Hydrological Center in order to obtain rainfall, discharge and sea level data collected during previous floods for the SOBEK model and a visit to the local dike department was planned. Unfortunately the Hydrological Center couldn't provide the right information without an invitation letter from the WRU.

FIGURE 152: WEIR IN THE HUONG RIVER TO PREVENT SALT INTRUSION WHEN THE DISCHARGE IN THE RIVER IS LOW

At local dike department there has been spoken with two persons working at the local dike department and one translator. The two men from the local dike department were from different departments. One was from the storm department and the other from the department of floods and reservoirs. After a short introduction by the project team questions have been asked and documents are consulted and shared. The local dike department was well-willing to provide us with required information.

FIGURE 153: RIVERBANKS WITH NO PROTECTION STRUCTURES FOR FLOODING OR EROSION

FIGURE 154: RIVERBANK WITH EROSION PROTECTION

FINDINGS

During the field trip, a lot of new and interesting information and insights have been collected that will have a large impact on the process of the project. In this chapter, a short list of findings will be made. These findings can be seen as a list of clarifications that we needed, searched for or stumbled upon during the week in Hue. It contains insights on the landscape, living environment, land use and state of the water defence system, which can be used in the remainder of the project.

LAND USE

- The main use of land, agriculture, starts very close to the city. This means that there is a very steep decline in value of the land present at the edge of the city.
- The main blind spot, consisting of a large white area on the map, is mainly wasteland. The distinctive white color and lack of people and trees can be accounted to chemical assaults during the Second Indochina War in the second half of last century.
- Large areas of the coast of the lagoon are filled with aquacultural farms.
- Outside of Hue, the main buildings and houses are placed directly next or a few meters from the main roads
- Flooding prevents the farmers to grow and harvest their lands for a significant part of the year

LIVING ENVIRONMENT

- The inhabitants are up to a great extent prepared to live with water instead of fighting it
- Most houses are made of stone and concrete
- Most houses don't have their valuable belongings directly on the main floor
- The Huong River is being used as a source for everything, from waste to washing
- The infrastructure is suffering greatly from the floods

STATE OF THE WATER DEFENSE SYSTEM

- Water defence system around the lagoon is in place and coordinated by the local Dike Department and the surrounding communes
- Water defence system around the river is mostly absent
- Structures around the river are mostly local erosion control or irrigation connections
- Communes around the river have to provide for their own water defence and water control structures
- Defence against flooding from the sea is mostly in place in the form of dunes between the sea and the lagoon
- The main focus of the current water defence is to prevent the highest floods by storing the flood peaks in the reservoirs upstream, milder floods are accepted

The findings mentioned above will be considered and used to form, change and clarify the rest of the report.

APPENDIX C: TABLE OF DISASTERS IN VIETNAM

Natural disaster	No. people killed, missing / injured	Major impacts *(official data supplied by the CCFSC)*	Estimated loss (USDm)
Floods in the Red River Delta region, 1996	89, 0 / 82	- 84,265 houses collapsed and flooded - 1,313 class rooms damaged - 57,900 ha of rice paddy flooded - 11,675 ha of farmland damaged - 806 ha of fish and shrimp ponds flooded - 178 tons of fish and shrimps destroyed	30
Typhoon Linda in Ca Mau province, 1997	778, 2123 / 1232	- 312,456 houses collapsed and damaged - 7,151 schools damaged - 348 hospitals and health centres flooded and damaged - 323,050 ha of rice fields damaged - 57,751 ha of farmland flooded and damaged - 136,334 ha of fish ponds flooded - 7,753 ships and boats damaged	450
Droughts in 1997, 1998		- heavy crop losses in especially the central regions	NA
Floods in the Central Region, 1999	721, 35 / 476	- More than 1 million houses damaged - 5,915 class rooms damaged - 701 hospitals and health centres flooded/damaged - 67,354 ha of rice fields flooded - 98,109 ha of farmland damaged - 41,508 ha of fish and shrimp ponds flooded - 1,335 tons of fish and shrimps destroyed - 2,232 ships and boats sunk	300
River floods in the Mekong Delta, 2000	481, 1 / 6	- 895,499 houses damaged - 12,909 class rooms damaged - 379 hospitals and health centres flooded/damaged - 401,342 ha of rice fields flooded and damaged - 85,234 ha of farmland damaged - 16,215 ha of fish and shrimp ponds flooded - 2,484 tons of fish and shrimps destroyed	250
River floods in the Mekong Delta, 2001	393, 1 / 0	- 345,238 houses damaged - 5,315 class rooms damaged - 20,690 ha of rice fields flooded and damaged - 1,872 ha of farmland damaged - 4,580 ha of fish and shrimp ponds flooded - 969 tons of fish and shrimps destroyed	100
Damrey typhoon in Northern and North Central Coast regions, 2005	10, 0 / 11	- 113,431 houses damaged - 3,922 class rooms damaged - 2,227,627 ha of rice fields flooded and damaged - 55,216 ha of farmland damaged - 21,193 ha of fish and shrimp ponds flooded - 1,300 tons of fish and shrimps destroyed	200
Chanchu typhoon in the Central Region, 2006	19, 249 / 1	- fishing boats sunk in the East Sea (=South China Sea)	2
Xangsane Typhoon in the Central Region, 2006	72, 4 / 532	- 349,348 houses collapsed and damaged - 5,236 class rooms damaged - 21,548 ha of rice fields flooded and damaged - 3,974 ha of fish and shrimp ponds damaged - 494 tons of fish and shrimps destroyed - 951 ships and boats sunk	650

Source: (Chaudhry and Ruysschaert 2007)

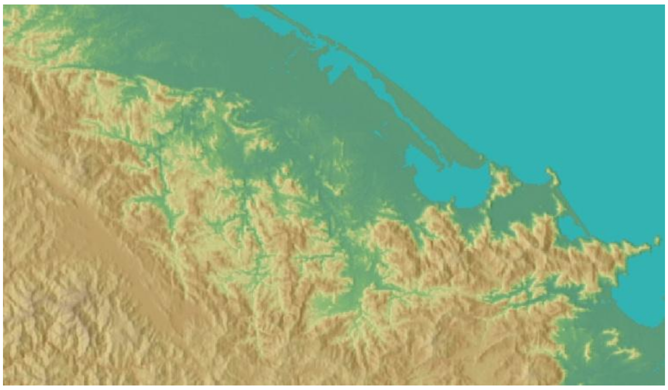


FIGURE 156: THE RELIEF MAP OF THE THUA THIEN-HUE PROVINCE

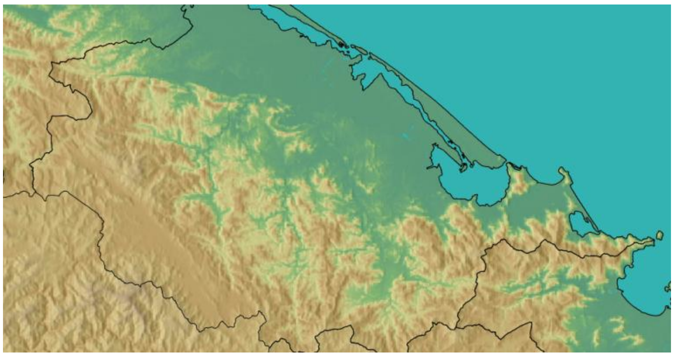


FIGURE 155: THE RELIEF MAP WITH BORDERS OF THE THUA THIEN-HUE PROVINCE

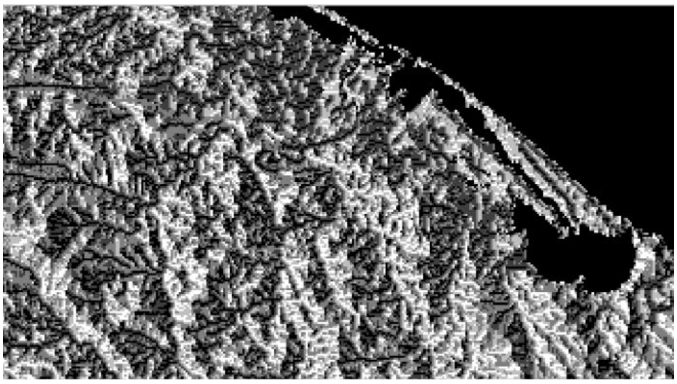


FIGURE 157: THE DRAINAGE ACCUMULATION MAP OF THE THUA THIEN-HUE PROVINCE

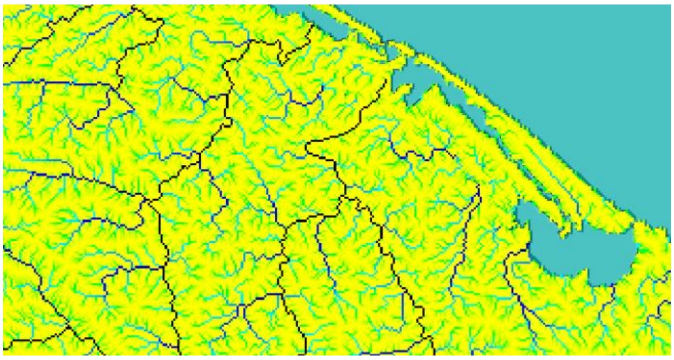


FIGURE 158: THE DRAINAGE DIRECTION MAP OF THE THUA THIEN-HUE PROVINCE

The catchment area can be calculated with the use of an altitude map and with a program called Quantum GIS. The program calculate the drainage direction and from that the place of the rivers can be calculated and also the catchment areas.

The altitude map is downloaded from http://earthexplorer.usgs.gov/. It is a GMTED2010 raster with a resolution of 250 x 250 meter. With the program called Quantum GIS in combination with GRASS a relief map is created. The coordinate reference system in which one should work can be found on the internet. For this region in the world one should use the WGS 84 / UTM zone 48N projection. This map is created by combining the downloaded map with a shadow map. The shadow map is created with a GRASS function and the downloaded map as input. The relief map is shown in Figure 156.

The next step is to put the province and the land borders in the map. www.GADM.org is a site where all the countries and province borders can be downloaded as a vector for GIS. By changing the reference coordinate system of the vector layer in the used reference coordinate system it will be projected on the map. This is shown in Figure 155.

From this map the watersheds can be determined by do some operation in GRASS and the command shell. Use the r.watershed function in GRASS and change the non values cells of the raster into NULL()) cells in the command shell to avoid conflicts in the next step. The results of these operations area are shown in Figure 157 and Figure 158. In Figure 157 the drainage directions are shown. The drainage direction is calculated by assuming that the water

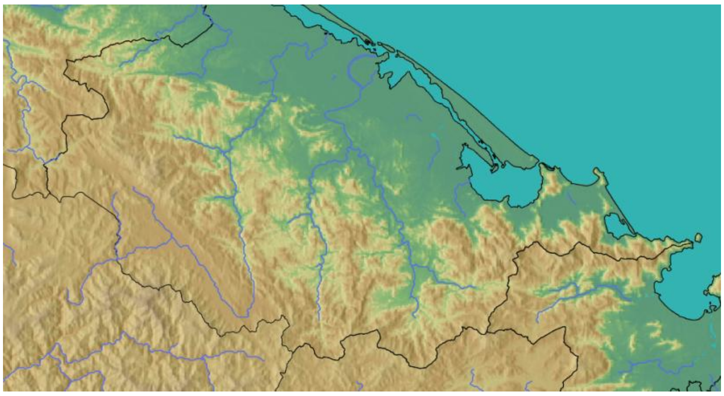


FIGURE 159: THE RIVERS IN THE THUA THIEN-HUE

flows from a raster to the lowest neighboring raster. In the other map, one can see the drainage accumulation, which shows the path that the water takes. The color of a raster will change, if an amount of cells drained toward the raster considered. From this map rivers can be localized. By making a vector from this map the rivers can be imported into the map. This is shown in Figure 159.

The catchment can be determined with the same GRASS function. One needs to define how much cells are included in one watershed. The more cells the bigger the catchment area. The 1900, 500 and 100 cells catchments are shown in Figure 160. The 100 cells catchment is used to define the catchments of the reservoirs. To get a better approximation of the catchment area a lower value is needed. But for this project this would be time consuming, and a 100 cells catchment will already give a good approximation of the area.

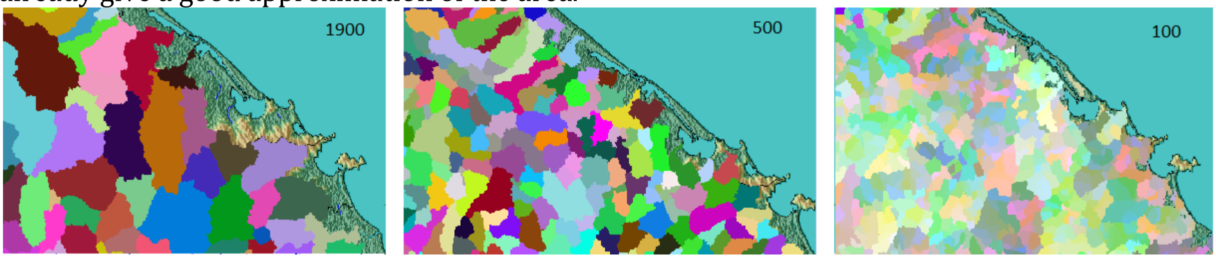


FIGURE 160: THE CATCHMENTS WHEN 1900,500 AND 100 RASTER CELLS ARE INCLUDED. THE LESS RASTER CELLS THE MORE ACCURATE THE CATCHMENT AREA CAN BE DETERMINED

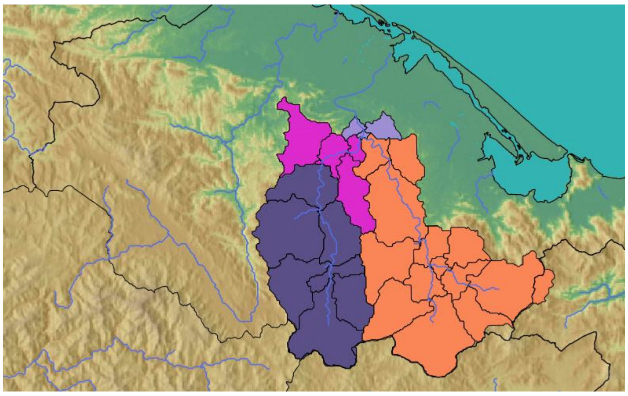


FIGURE 161: THE CATCHMENTS USED IN THE REPORT DIVIDED INTO SEVERAL SUB CATCHMENTS

The next step is to make a raster layer which includes only the raster that is preferred. The result can be seen in Figure 161.

By making a vector from this GRASS raster, one can do some vector statistics with the use of the vector calculator. One of the options is to calculate the area of the vector. One can calculate the area of all the catchments separately, but handier is to use the dissolve function first to create one catchment of all the sub catchments and then use to vector calculator to calculate the catchment area. The result is shown in Figure 162.

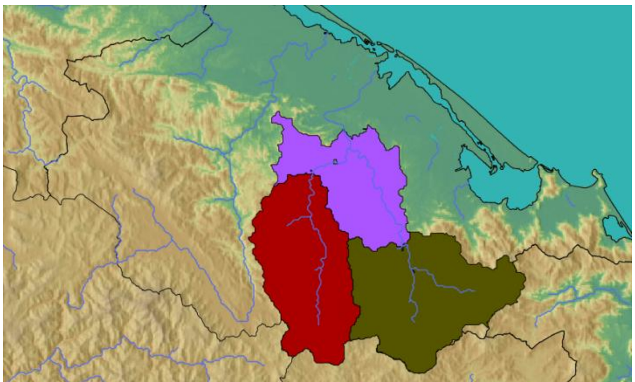


FIGURE 162: THE CATCHMENTS USED IN THE REPORT ALL AS ONE PIECE

Now, the map includes the rivers and relief and also the watershed area is known. The reservoirs are created with the function xy.lake in GRASS. One needs to know the location of the dam and the height. Also the GRASS calculation region must be adapted to only the area in which the reservoir is located, otherwise GRASS creates two lakes on both sides of the dam. The only input that is needed is the height of the dam. This information is found in a booklet (NARENCA 2012). The result is shown in Figure 163.

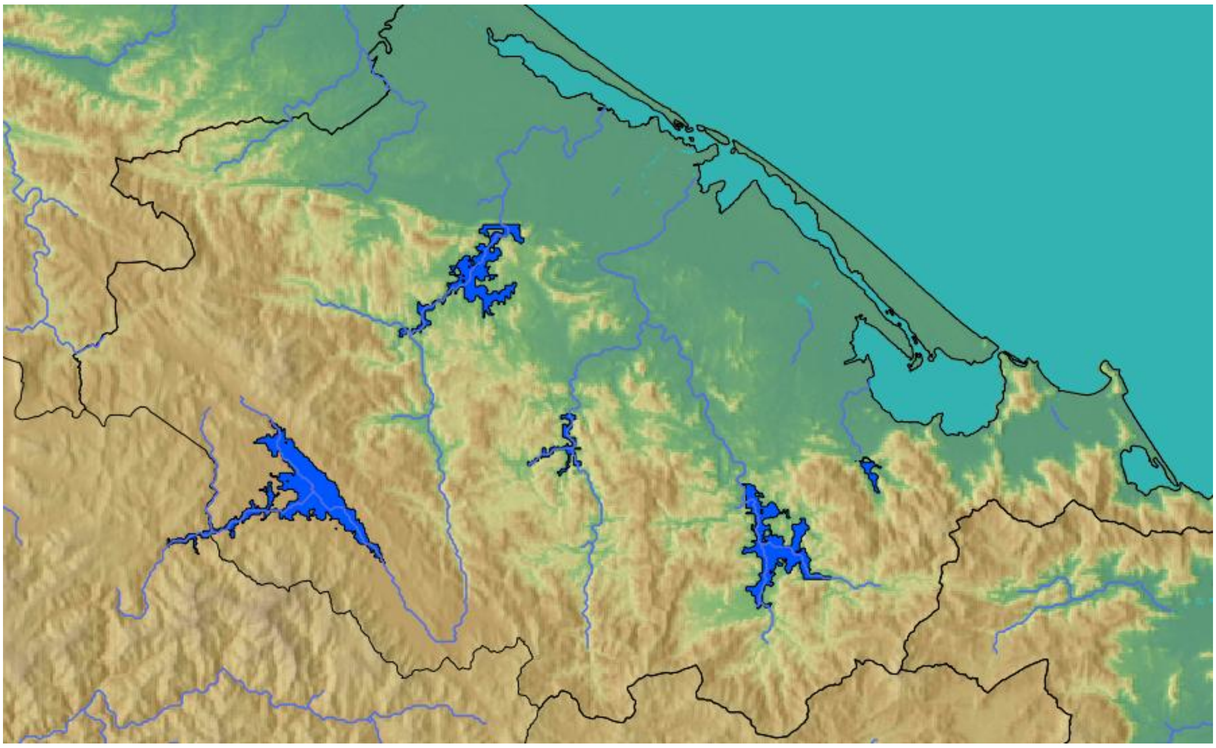


FIGURE 163: THE THUA THIEN-HUE PROVINCE WITH THE RIVERS AND THE RESERVOIRS

APPENDIX E: COST OF A FLOODING

First of all an introduction is given about the global domestic rate of the province, its growth in the past decades and its distribution over the different economic sectors. This distribution is used to assess the damage of a flood in a structured way so that every sector of any importance is incorporated in the model. The costs for each sector have been investigated in more detail based on some assumptions. Afterwards, the model is calibrated for the flood of 2007 and used for several floods to check the effectiveness of the taken measures. Afterwards, the total net present value of the costs of both the measures and the reference scenario are checked after a period of 50 years to check for the profits in terms of money.

GROSS DOMESTIC PRODUCT PROVINCE OF THUA TIEN HUE

In 2006, the gross domestic product (GDP) of the province was approximately 9600 billion VND, for which 530.000 laboured people were responsible. This brings the average annual wage to more or less 16 million VND per employee. The total population of the province comes down to 1.1 million people. The GDP per capita is approximately 8 million VND per year, which is just a little more than one US dollar per day (MoNRE, 2011).

In the last couple of decades the GDP of the province has increased enormously. In the most recent years the growth rate was on average about 15%. On the other hand there is a huge inflation rate. This rapid growth should be incorporated in the model together with the rate of inflation when the future costs of floods are translated to the net present value by means of the discount rate. A discount rate of 1-2% is assumed to be correct (Cong, 2013).

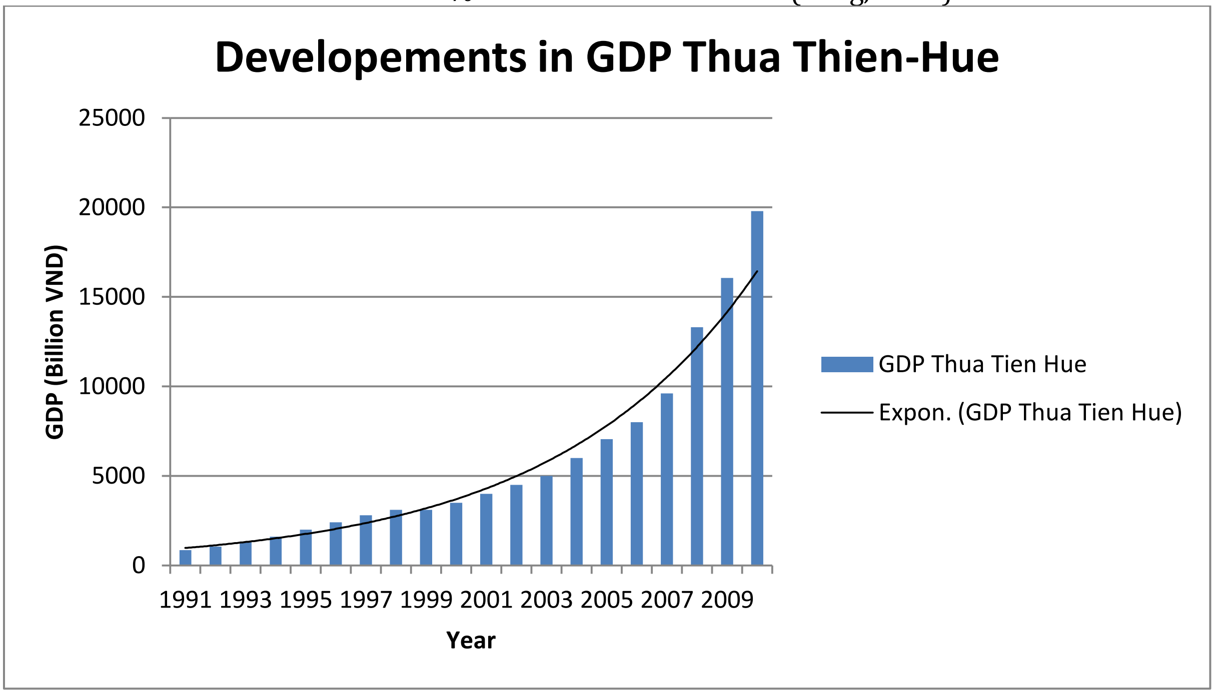


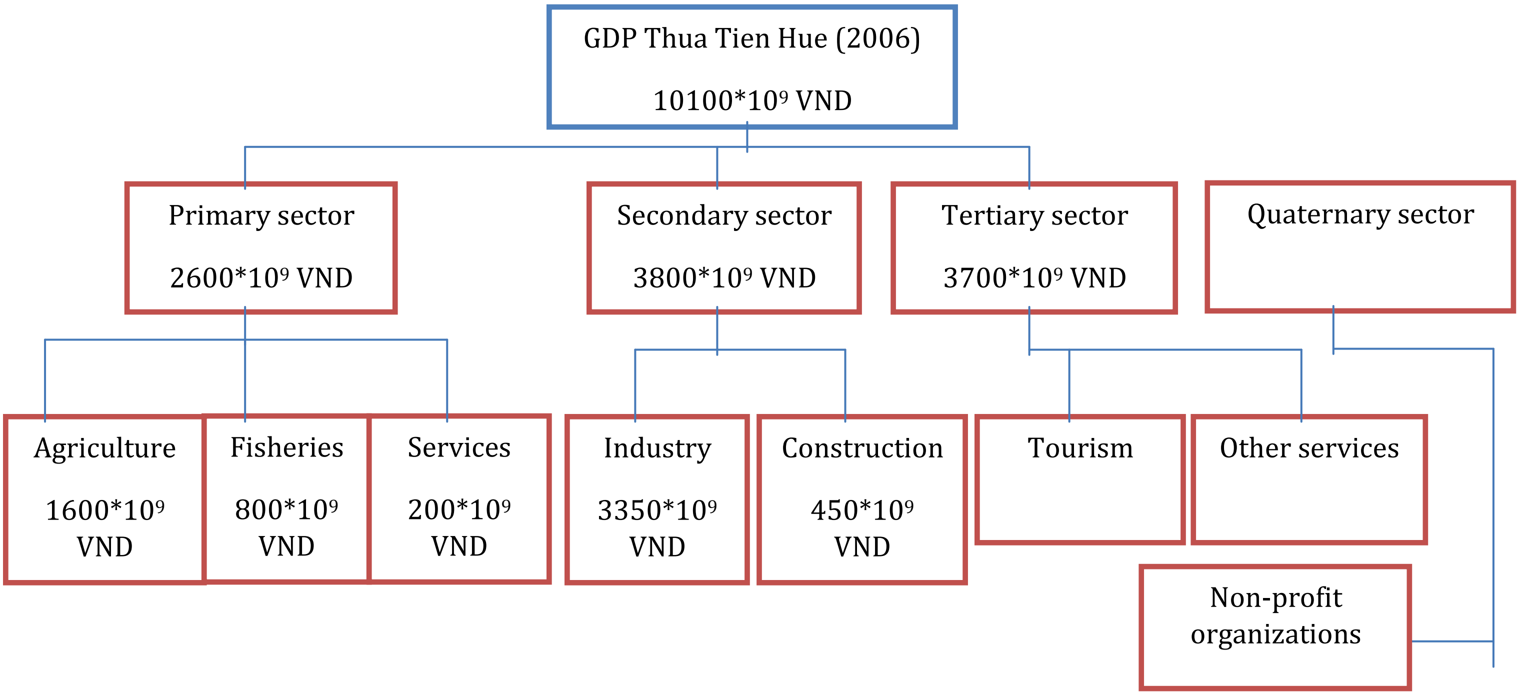
FIGURE 164: GROWTH OF GDP IN THE PROVINCE OF THUA THIEN-HUE, TRAN KIM THANH

The annual income has been split up into contributions from the four economic sectors. This makes it, together with the land use- and inundation map, possible to obtain more insight into the distribution of damages caused by a single flood.

The primary sector is the economic sector which makes directly use of the natural resources in order to earn money. In the province of Hue, this sector consists of agriculture, aquaculture and services which are related to these two.

The secondary sector is responsible for the manufacturing of the natural resources. It consists of both industries and construction.
The tertiary sector (also called the service sector) consists of activities which are related to the sharing of time, knowledge and services. In opposite to the first two sectors no physical products are being created. This sector consists for example on tourism, shops, transportation etcetera.
At last, the quaternary consist of non-profit organisations like the government, universities and hospitals.

The distribution of the GDP over the sectors is visualized in the diagram below.



Now that the distribution is known, a model will be set up to assess the damage of a flood for each of the individual sectors.

DAMAGE CAUSED BY A FLOOD

The estimation of the total costs can be divided into direct costs and indirect costs, measurable and non-measurable costs. The cost- benefit analysis performed in this report has been based on the direct costs of a flood and thus gives the lower boundary of the total costs of damage caused by a single flood event.
The costs of the flood of a certain part of the area are based on the land use, which is described earlier on in this report, in combination with flood maps for events with a certain return period. The total damage of a flood has been split up into the four sectors mentioned above and the costs of damage to houses.

Note: this cost analysis has been based on very crude assumptions and estimations and should therefore be used with great care. Further research should be done in order to refine this model.

DAMAGE TO HOUSES

The damage to houses caused by floods consists of loss of furniture, electrical breakdown, physical damage to houses and cleaning works.

The damage to houses has been based on the available maps on the population density. In order to perform a thorough analysis, a damage function which relates the depth of a flood to the damage to houses should be derived (A.K. Pistrika , S.N. Jonkman 2010). This damage function is defined as the ratio between the damage to a house and its market value.

The damage to houses can be estimated by the following formula:

$$D_h = \frac{A_i * \rho_i}{I} * P_h * \alpha(h) \qquad (1.1)$$

D_h = Damage to all houses in a certain area caused by a single flood
I = Number of people per household
A_i = Inundated area (km²)
ρ_i = population density (inhabitants/km²)
P_h = Market value of a house (in €)
α(h) = Damage factor to houses, which is a function of the inundation depth h:

TABLE 19: DAMAGE FACTOR WITH DIFFERENT INUNDATION DEPTHS

Inundation depth (meters)	Damage factor α
0-1 m	0,05
1-2 m	0,2
2-3 m	0,4
>3 m	0,5

The market value of a certain house depends very much on the location: in the center of Hue the value of a house can be up to €350,-/m², while in the non-urban areas the houses are a lot less valuable. On average, the value of a non-urban house is approximately €1500,- ($2000,-, ESCAP, AIT 2012). Furthermore, within a certain area there is a lot of variation in the quality and value of the houses as well. For the sake of simplicity, the houses have been divided into two categories: houses in urban area and houses in non-urban area.
The following housing prices are assumed:

TABLE 20: THE ASSUMED PRICE OF A HOUSE

Area	Assumed price of a house
Urban area	€10.000,-
Non-urban area	€1.500,-

The population densities are estimated both on the available literature of the land use and on our own experiences gained during the field trip.

The number of people per household is assumed to be 3.8 (Nguyen Thanh Binh, 2011).

DAMAGE TO THE PRIMARY SECTOR

The damage to the primary sector is caused by losses of harvest and fish farms.

DAMAGE TO AGRICULTURE

The damage to agriculture is estimated in a different way. Since most of the agricultural area is covered by rice fields, (MoNRE 2008)this type of land use is taken as representative for the whole agricultural area. In order to assess the costs, the assumption is made that the farmers know far ahead when the flood period arrives. This implies that the farmers harvest all of their rice before the land is flooded. The only financial damage from which the farmers suffer is the loss of capacity during the wet period. The annual loss is estimated in the following way:

$$D_a = A_{i;a} * P_r * C_r * t_I \qquad (1.2)$$

D_a = Loss of income for the farmers on a yearly basis
$A_{i;a}$ = Surface of inundated agricultural ground (ha)
P_r = Rice production (kg/ha/year)
C_r = Costs of rice (€/kg)
t_I = ratio inundation days/fertile days

According to the report of MoNRE, a total of 250 million kilograms of rice is harvested on a yearly basis, distributed over an area of 50.000 hectares. This leads to a productivity of 5 tons of rice per hectare. The annual profits are estimated to be 1050 billion Vietnamese Dongs per year, which is approximately €37.500.000,- (using the exchange rate of 28.000 VND = €1,-). This brings the price of rice to €0,15/kg. This amount is based on a fertile period of 8 months. The loss of profits comes down to the production of 4 months, which is equal to half of the fertile period.

The estimated annual damage to agricultural areas is:

$$\frac{D_a}{A_{i;a}} = P_r * C_r * t_I = 5000 * 0{,}15 * 0{,}5 = €375,-per\ hectare$$

DAMAGE TO AQUACULTURE

Almost all of the aquaculture consists of shrimp farms. The damage to shrimp farms can be split up into two parts: at first the damage caused by the loss of shrimp and in the second place the maintenance and repairing works to the farms themselves after a flood. The damages are assumed to be a percentage of the yearly shrimp production.

$$D_s = A_{i;s} * P_s * C_s * L_s \qquad (1.3)$$

D_s = Damage to shrimp farms
$A_{i;s}$ = Inundated area of shrimp farms (ha)
P_s = Annual shrimp production (kg/ha)
C_s = Price of shrimps (€/kg)
L_s = Percentage of annual income lost during a flood

3800 tons of shrimps are harvested on annual basis from an area of 3000 hectares of shrimp farms (MoNRE 2008). This brings the productivity to approximately 1.3 tons per hectare per year.

The prices of shrimps is assumed to be €5,-/kg, which is a reasonable estimation for shrimps of the size 30 shrimps/kg .

The average lifetime of a shrimp is assumed to be 6 months, so assuming that all shrimps are lost during a flood, on average 3 months of growth will be lost. The time and costs of maintenance and repairing costs are assumed to be equal to the costs of loss of growth. This brings the percentage of annual income lost during a flood to 50%.

By filling in the information above in (1.4) one finds that the costs of the flood of fish farms are estimated to be €3250,- per hectare.

DAMAGE TO THE SECONDARY SECTOR

The damage to the secondary sector consists of damage to fabrication and damage to construction. Factories might be damaged and fabrication- and construction works will be paused during a flood. Physical damage to construction sites is neglected. It is assumed that all construction takes place in the urban areas (which is of course not fully correct) while all the factories are assumed to be located in the rural areas because of lower ground prices. Since no data about the positions of factories is found, it is assumed that they are randomly distributed over the rural area of the province.

$$D_{sec} = t_i * A_{i;u} * P_c + t_i * A_{i;r} * P_f + A_{i;r} * \gamma_r * P_f \quad (1.4)$$

D_{sec} = Damage to the secondary sector
t_i = ratio inproductive days/total days in a year
$A_{i;u}$ = Inundated urban area (ha)
P_c = Productivity of construction (€/ha/year)
$A_{i;r}$ = Inundated rural area (ha)
P_r = Productivity of factories (€/ha/year)
γ_r = Coefficient (-)

The first two terms in equation (2.1) take into account the loss of productivity during the flood while the third factor represents the physical damage to factories.

One week of non-production is assumed to be needed in order to clear up the mess of a single flood, which is approximately 2% of the year.

The residential area of the province covers about 3500 hectares of land (MoNRE 2008). This brings the annual productivity for the construction to approximately €4600,-/hectare/year. One week of non-production of construction works comes down to an estimated cost of €92,-/hectare.

The rural area covers about 100.000 hectares. The productivity of the factories comes down to 1200,-/hectare/year. This brings the costs of the non-production of one week of the factories to €24,-/hectare of inundated rural area.

When a factor is flooded, it is assumed that physical damage consists of 10% of the yearly income. This brings the costs of physical damage to €120,-/hectare of inundated rural area.

$$D_{sec} = 92 * A_{i;u} + (24 + 120) * A_{i;r} = 92 * A_{i;u} + 144 * A_{i;r}$$

DAMAGE TO THE TERTIARY SECTOR

The tertiary sector suffers from floods because of a loss of income due to a setback in the number of tourists and physical damage to hotels, shops, restaurants etcetera. These damages are closely related to the area of urban areas which are inundated since most of the (touristic) services take place here.

$$D_t = \delta_1 * A_{i;u} * P_t \quad (1.5)$$

D_t = Damage to the tertiary sector
δ_1 = Coefficient (-)
$A_{i;urban}$ = Inundated urban area (ha)
P_t = Annual productivity of the tertiary sector (€/hectares/year)

It is assumed that 5% of the yearly income is lost due to a flood in inundated areas. The productivity of the tertiary sector, which is spread out over the 3500 hectares of urban area comes down to €37.750,- per hectare per year. A single flood costs about €1900,-/hectare of inundated urban area for the tertiary sector.

DAMAGE TO THE QUATERNARY SECTOR (REMAINING COSTS)

The last part of the direct costs consists of the damage to the quaternary sector. These costs include damage to infrastructure, damage to special structures like ports, hospitals, dikes, dams and airports and the costs to clear away the mess. Little data is available for these costs, therefore these costs should be found by calibration of the model. These costs are assumed to be a percentage of all the other costs combined.

$$D_r = (D_h + D_a + D_s + D_{sec} + D_t) * \beta \qquad (1.6)$$

D_r = The remaining costs of damage due to a single flood
β = Factor which relates the remaining costs to the costs mentioned above

The measurable, direct damage is the sum of the four components:

$$TC = D_h + D_a + D_s + D_{sec} + D_t + D_q \qquad (1.7)$$

TC = Total costs of a flood in a certain area

CALIBRATION OF THE MODEL

The flood of 2007, which is assumed to be a 1 in 5 years flood, has been used for the calibration of the model. The input of the model has been derived from the paper "Assessing damage of flood by using data in Thuan Tien – Hue Province" by Tran Dinh Lan.

TABLE 21: INPUT OF THE MODEL DERIVED FROM A PAPER OF TRAN DINH LAN (LAN AND VAN THAO 2011)

Landuse/cover types	Huong Thuy District (ha)	Huong Tra District (ha)	Phong Dien District (ha)	Phu Loc District (ha)	Phu Vang District (ha)	Quang Dien District (ha)	Hue City (ha)
Rural area	47.4	42.9	39.7	194.1	85.2	45.1	0.0
Aquacalture ponds	445.5	73.2	69.7	200.4	314.8	335.4	0.0
1 crop rice + 1 crop vegetables	41.1	118.0	160.6	310.6	0.0	102.2	62.8
2 crop rice	3221.7	2975.2	2626.1	1990.4	6286.2	3941.6	899.0
2 crop rice + 1 crop vegetables	0.0	331.2	767.9	0.0	0.0	563.8	40.2
Vegetables + industrial tree crops	0.0	167.8	117.5	48.0	140.0	47.2	10.5
Fields and gardens	22.3	0.0	0.0	0.0	0.0	0.0	0.0
Phu Bai Airport	5.6	0.0	0.0	0.0	0.0	0.0	0.0
Urban rea	0.0	0.0	0.0	0.0	0.0	0.0	50.1

Table 21 has been reduced to Table 22.

TABLE 22: TABLE WITH THE LANDUSE AND THE FLOOD EXTEND

Landuse	Flooded area (ha)	Population density (inhabitants/ha)
Agriculture	25.000	0
Aquaculture	1.437	0
Urban area	50	400
Non-urban area	454	5

The distribution of inundation depth over the houses is assumed to be as Table 23(Tran Dinh Lan).

TABLE 23: THE DISTRIBUTION OF THE INUNDATION DEPTH OVER THE HOUSES

Inundation depth	Percentage of houses
0-1 m	30%
1-2 m	30%
2-3 m	30%
>3 m	10%

According to the model, the total damage of the flood of 2007 to houses, primary sector, secondary sector and tertiary sector is together €31.6 million.

The output of the model has been compared to the costs depicted by Thanh which are shown in Table 24.

TABLE 24: THE COST AND VICTIMS OF THE RECENT YEARS DUE TO FLOODING AND STORMS

Year	Killed	Estimated loss (billion dong)	Year	Killed	Estimated (billion dong)
1990	18	56	**2001**	5	18
1991	10	20	**2002**	9	15
1992	8	12	**2003**	5	27
1993	6	14	**2004**	10	248
1994	1	1.2	**2005**	7	158
1995	20	60	**2006**	9	2931
1996	31	127	**2007**	23	1162
1997	1	11	**2008**	5	62
1998	31	169	**2009**	17	378
1999	352	1762	**2010**	15	227
2000	4	77	**2011**	13	799

The difference between the model and the real damage is €9.9 million and is caused by the damage caused by the flood to the quaternary sector. This difference is covered by the β-factor from formula (1.6). By filling in the known parameters, a β-factor of 0.3 in formula (1.6) is obtained.

USE OF THE MODEL

The flood maps from the SOBEK model and the land use map have been overlaid to get the input data for the model for different return periods. The yearly damage including the proposed measures has been compared to the damage without measures to get an idea of the profits from the measures. The following page gives an idea about the proportions of the different components of the costs.

											Damage (€*10^6)
		Inundated area (ha)	Damage (€/ha)								
Agriculture		25000	375								9,4
Aquaculture		1439	3250								4,7
		Depth 0-1 meters	Damage factor	Depth 1-2 meters	Damage factor	Depth 2-3 meters	Damage factor	Depth >3 meters	Damage factor	Market value house	
Houses	Urban houses	1579	0,05	1579	0,2	1579	0,4	526	0,5	10000	12,9
	Non-urban houses	681	0,05	681	0,2	681	0,4	227	0,5	1500	0,8
		Inundated urb area	Damage (€/ha)		Inundated non urb area (ha)		Damage (€/ha)				
Secundairy		50	92		25516		144				3,7
Tertiary		50	1900								0,1
Subtotal										Subtotal (€*10^6)	31,6
										Subtotal (VND*10^9)	884
								Subtotal (€*10^6)	β-factor		
Quaternary								31,6	0,3		9,5
										Total (€*10^6)	41,0
										Total (VND*10^9)	1149

FIGURE 165: EXCELSHEET WHICH IS USED TO ASSESS THE COSTS FOR A ONE IN FIVE FLOOD IN THE REFERENCE SCENARIO

It is assumed that the percentage of damage which is prevented by measures is equal for floods with different return periods. This leads to the following costs:

TABLE 25: DAMAGE CAUSED BY FLOODS WITH DIFFERENT RETURN PERIODS FOR DIFFERENT OPTIONS

Return period	Damage in reference case	Damage with bypass	Damage with Lake Hue
1 year	12,9	5,9	2,7
5 years	41,0	18,5	8,5
50 years	71,8	32,5	14,9

The costs of both solutions are based on reference cases. In the last decade, several reservoirs are constructed which are very much similar to the water retention area which is proposed in this report. The costs were all in the range between 70 million and 140 million Euros. For this project, the costs are assumed to be 150 million Euros to be on the safe side.

A reference period of 50 years is chosen to check if the solutions will pay off on the long term. During this period, it is assumed that the following floods occur: 40 floods with a return period of 1 year, 9 floods with a return period of 5 years and 1 flood with a return period of 50 years. These floods are randomly distributed over the period of 50 years.

The table on the next page gives the distribution of the floods with specific return periods over the reference period of 50 years.

TABLE 26: DISTRIBUTION OF FLOODS WITH CERTAIN RETURN PERIODS OVER THE REFERENCE PERIOD OF 50 YEARS FOR THE RETENTION AREA

Retention

return p	Year	Damage	Constr. Costs	Maintenance	Discount rate	NPV	Summation
1	1	2,7	150	1,5	0,02	151,2	151,2
1	2	2,7	0	1,5	0,02	4,0	155,2
5	3	8,5	0	1,5	0,02	9,4	164,6
1	4	2,7	0	1,5	0,02	3,9	168,5
1	5	2,7	0	1,5	0,02	3,8	172,2
1	6	2,7	0	1,5	0,02	3,7	175,9
1	7	2,7	0	1,5	0,02	3,6	179,6
5	8	8,5	0	1,5	0,02	8,5	188,1
1	9	2,7	0	1,5	0,02	3,5	191,6
1	10	2,7	0	1,5	0,02	3,4	195,0
1	11	2,7	0	1,5	0,02	3,4	198,4
1	12	2,7	0	1,5	0,02	3,3	201,7
5	13	8,5	0	1,5	0,02	7,7	209,4
1	14	2,7	0	1,5	0,02	3,2	212,6
1	15	2,7	0	1,5	0,02	3,1	215,7
1	16	2,7	0	1,5	0,02	3,0	218,7
1	17	2,7	0	1,5	0,02	3,0	221,7
5	18	8,5	0	1,5	0,02	7,0	228,7
1	19	2,7	0	1,5	0,02	2,9	231,6
1	20	2,7	0	1,5	0,02	2,8	234,4
1	21	2,7	0	1,5	0,02	2,8	237,2
1	22	2,7	0	1,5	0,02	2,7	239,9
50	23	14,9	0	1,5	0,02	10,4	250,2
1	24	2,7	0	1,5	0,02	2,6	252,8
1	25	2,7	0	1,5	0,02	2,5	255,4
1	26	2,7	0	1,5	0,02	2,5	257,9
1	27	2,7	0	1,5	0,02	2,4	260,3
5	28	8,5	0	1,5	0,02	5,7	266,1
1	29	2,7	0	1,5	0,02	2,4	268,4
1	30	2,7	0	1,5	0,02	2,3	270,7
1	31	2,7	0	1,5	0,02	2,3	273,0
1	32	2,7	0	1,5	0,02	2,2	275,2
5	33	8,5	0	1,5	0,02	5,2	280,4
1	34	2,7	0	1,5	0,02	2,1	282,6
1	35	2,7	0	1,5	0,02	2,1	284,6
1	36	2,7	0	1,5	0,02	2,0	286,7
1	37	2,7	0	1,5	0,02	2,0	288,7
5	38	8,5	0	1,5	0,02	4,7	293,4
1	39	2,7	0	1,5	0,02	1,9	295,3
1	40	2,7	0	1,5	0,02	1,9	297,2
1	41	2,7	0	1,5	0,02	1,9	299,1
1	42	2,7	0	1,5	0,02	1,8	300,9
5	43	8,5	0	1,5	0,02	4,3	305,2
1	44	2,7	0	1,5	0,02	1,7	306,9
1	45	2,7	0	1,5	0,02	1,7	308,6
1	46	2,7	0	1,5	0,02	1,7	310,3
1	47	2,7	0	1,5	0,02	1,6	312,0
5	48	8,5	0	1,5	0,02	3,9	315,8
1	49	2,7	0	1,5	0,02	1,6	317,4
1	50	2,7	0	1,5	0,02	1,6	319,0

The same has been done for the reference scenario and the option "Bypasses". This has resulted in the following graph:

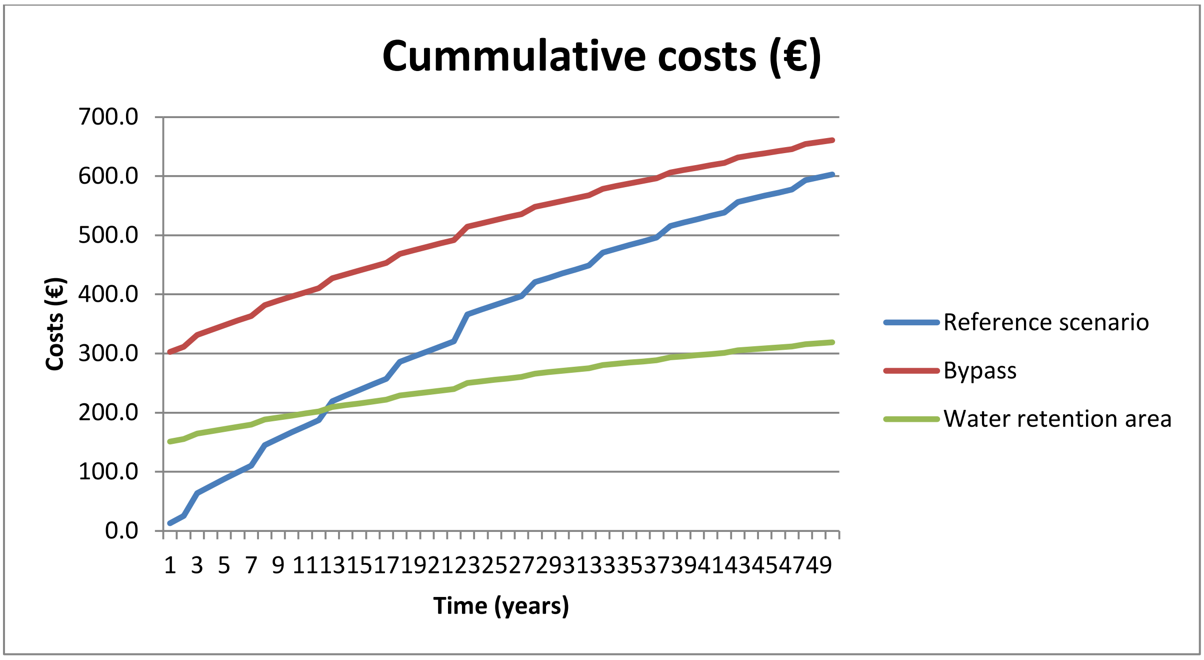


FIGURE 166: NET PRESENT VALUE OF THE SUMMATION OF COSTS OVER THE REFERENCE PERIOD OF 50 YEARS

CONCLUSION

It appears that the option "Water retention area" has a payback time of less than 15 years if a discount rate of 2% is assumed. After the reference period of 50 years, it even turns out that the net present value of the costs of this option is halve of that of the "Do nothing-scenario".
The option "Bypass" is less lucrative. This is caused both by higher initial costs and a lower effectiveness. The total costs after a period of 50 years are even larger than if nothing changes.

Although the results are very promising, this graph can at present not yet be used as a basis of decision-making. There are still too many uncertainties, simplifications and assumptions which still have to be verified and refined in order to be reliable. This graph can only be used to get a rough idea about the profits and to convince decision makers to continue to further investigate this option.

SOURCES

Information about Model:
(Pistrika and Jonkman 2010)
Information for the model:
(MoNRE 2008)
Cost:
(Lightner FAO)
(FAO 2013)
(VSN 2013)
(Binh 2011)
(ESCAP 2012)

APPENDIX F: MATLAB FILE FOR CALCULATION OF THE NEEDED DAM VOLUME

The needed volume of earth that is needed for the construction of the dam is calculated in this appendix with the use of Matlab.

The cross section information is from the SOBEK model is made by Dr. Nghiem Tien Lam. A section of this cross section information is shown in Table 27. In the report is assumed that the surface level between the locations is constant.

To calculate the volume, a calculating program called Matlab is used. The m-file to calculate the volume is shown in Figure 168.

TABLE 27: THE DATA.TXT FILE FROM LOCATION 80 TILL 240

Location x	Surface height location x
80	13.09
90	12.05
100	11.02
110	10.11
120	9.20
130	8.29
140	7.38
150	6.47
160	5.56
170	4.35
180	3.04
190	1.73
200	0.42
210	-0.89
220	-1.90
230	-1.95
240	-2.75

The result is 890.000 cubic meter of earth is needed to create the dam if the total dam height is 21 meter and the top width is 8 meters. The sections of the dam are shown in Figure 167.

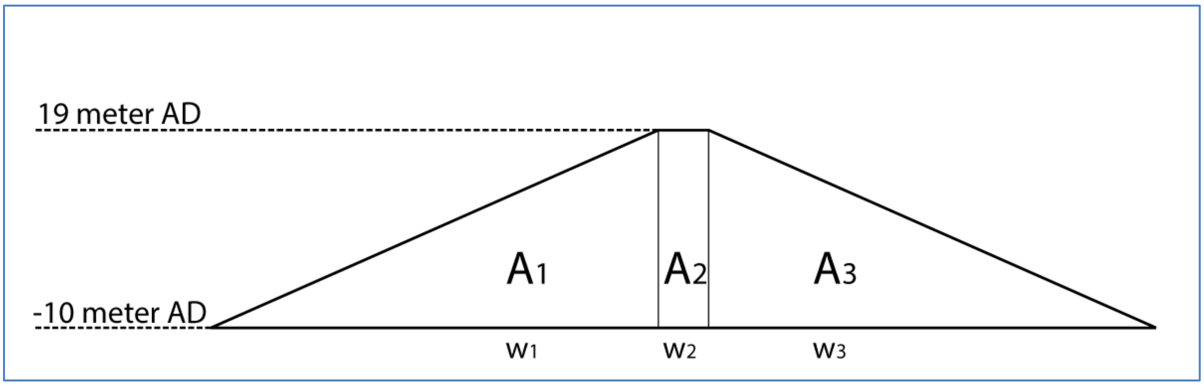


FIGURE 167: SECTIONS OF THE DAM FOR CALCULATING THE SURFACE AT X

This file calculates the needed volume of the dam

Needed parameters

```
data = load('data.txt'); % Load data of the land height
x = data(:,1);      % width 0-800 m gives the x coordinate of the elevation points the sections have a width of 10 meters
y = (data(:,2));        % elevation points gives the profile of the surface
S=size(y);
interval=10;        % The amount of intervals for which the volume is calculated 10 makes the total interval 1 meter
angle=18;           % The angle between the dam and ground
height_of_dam=21;   % The needed dam height
width_top=8;        % The width of the top of the dam
V=0;
```

This loop calculate the volume of the dam

```
for n=1:S(1)                        %
    if(height_of_dam>y(n))          % If the height of the elevaltion exceeeds 21 meter than it is not needed to calculate the volume, because no dam is needed here
        h=height_of_dam-y(n);       % This calculates the height of the dam from ground surface
        w1=h/tand(angle);           % Calculate the width of the dam at x
        A1=w1*h*0.5;                % Calculate the surface of the triangle shape dam part at x
        W=w1*2+width_top;           % Calculate the total width on the suface
        A2=h*width_top;             % Calculate the surface of the square shape dam part at x
        V=V+((A1*2+A2)*interval); % Calculate the total volume of the dam on the right side of part x
    end
end
V(1)  %Give the needed volume of the dam
```

```
ans =

   8.9299e+05
```

FIGURE 168: THE M-FILE THAT IS USED TO CALCULATE THE NEEDED DAM VOLUME

APPENDIX G: LIST OF FIGURE AND TABLES

LIST OF FIGURES

LIST OF TABLES