

Flood Damage Map for the Huong River Basin

*Based on inundation depths, land use types and population density,
using depth-damage curves, maximum damage values and
depth-mortality curves.*

Jorik Chen, December 2007

HANOI UNIVERSITY
of
SCIENCE
Vietnam National University



University of Twente
Enschede - The Netherlands

This is a Bachelor Thesis for the study of Civil Engineering at the University of Twente, The Netherlands. The assignment was carried out from September until December 2007 at the Hanoi University of Science - VNU.

***Flood Damage Map for the Huong River Basin – Bachelor Thesis
Jorik Chen - s0065552 - 13th of December 2007***

*University of Twente, The Netherlands
Faculty of Constructing Sciences, Civil Engineering
Tutors: Dr. J.L. de Kok
Dr. M.S. Krol
Ir. J.A.E.B. Janssen*

*Hanoi University of Science (VNU)
Faculty of Hydro-Meteorology and Oceanography,
Department of Hydrology
Tutors: Dr. Nguyen Tien Giang
Assoc. Prof. Dr. Nguyen Hun Khai*

Abstract

In the last decade, the basin of the Huong River has been flooded several times causing damage all over the Thua Thien Hué Province. These floods are initiated by tropical storms which are accompanied by heavy rainfall. Economic and social consequences are significant and should be restricted in the future. This assignment contributes to creating an insight in the consequences, by developing a damage map based on inundation depths and the land use in the Huong River Basin.

At the Vietnam National University of Hanoi, HEC-RAS software has been used to develop a model for inundation depths. Applying the discharges of the November 1999 flood in the Thua Thien Hué Province, an inundation map is created that is used as input for this assignment. Together with a damage function and spatial data about the settlements, the infrastructure and the agriculture, the damage map is created.

The damage function consists of depth-damage curves and maximum damage values which are compatible to the several land use types. These are collected from preliminary damage assessments and literature concerning damage functions. The damage is calculated per land use type by multiplying the damage factor derived from the depth-damage curve with the maximum damage for the particular grid cell.

The HEC-RAS inundation map that is used as input for the damage map, is compared with an observed inundation map of the November 1999 flood. The HEC-RAS model seems to be insufficient to simulate the inundated surface, but the data within its prediction of the inundated areas are qualitative more significant: 26 percent of this data is similar to the observed data.

Also the accumulated damage of the resulting damage map is compared with the existing data of the November 1999 flood. The total damage based on the damage map corresponds reasonably with the reported damage in November 1999. Determining the damages and inundation surface per land use, it can be concluded that the rural settlements suffer most in case of a flood. This land use type should obtain the most attention for reducing flood consequences since it has great vulnerability for flooding and the fact that it is often located in heavily inundated areas.

The method implemented for the damage map is also used for the mortality in the Huong River Basin, but now using the inundation depths and the population density for input. However, the obtained depth-mortality curve seems not to be valid since during the comparison with the data of the November 1999 flood, the mortality turned out to be highly overestimated.

Acknowledgements

During this assignment in Vietnam I met many people that made my stay abroad besides an interesting assignment also a beautiful experience.

I'd like to thank Michiel for his accompany in Hanoi and surroundings. Our shared interests have made life in Vietnam fun, especially our motorbike trips through the Hanoi traffic towards another unique experience was joyful. At the faculty, during dinner, exploring the city, cruising to Hué, playing chess, drinking sinh to, we've had a lot of fun!

Dr. Giang made my assignment possible and besides becoming a father, having no sleep, being the busiest person in Hanoi and carrying huge responsibilities, he was able to make time for me. I have incredible much respect for his ability to do everything and I wish him extremely much luck and happiness with his wife and daughter.

Dr. Ahn was available to explain whatever I wanted to know about everything, and his care about Michiel and me was truthfully. I enjoyed his cordiality and his commitment. I know for sure that with his commitment, he is able to reach the World Cup with just the Faculty-team!

I want to thank Thuy and Phuong for their efforts and availability for my questions in the early beginning of my assignment. Further on, Mrs. Lieu and Mr. Tuyet have not only accommodated me perfectly, their concern was touching and very sweet. Mrs. Lieu, you serve the best spring rolls of Vietnam!

All the friends I made in Hanoi were unbelievable kind to me and showed me the Vietnamese life that is unreachable for a common foreigner. Trang, Nhug, miss Hanoi Post, Quyen, thanks for your kindness and open-heartedness. Dung was always available to do great things in and around Hanoi and has introduced me to motorbike riding and the difficult life of a Vietnamese student. We've laughed a lot, I'm glad I met you.

Off course I want to mention the efforts of Judith and Maarten to take over the responsibility of Jean-Luc, their comments helped me much creating my report. At last I want to wish Jean-Luc good health, since an accident unfortunately let him be capable to only supervise the first stage of my assignment.

*Jorik Chen,
Hanoi, Vietnam, 13th of December 2007.*

Table of Contents

CHAPTER 1. INTRODUCTION	1
1.1. GENERAL INFORMATION ABOUT HUONG RIVER BASIN	1
1.2. PRELIMINARY RESEARCH	1
1.3. AIM OF THE RESEARCH	2
1.4. RESEARCH QUESTION	2
1.4.1. Sub questions	2
CHAPTER 2. METHODOLOGY	3
2.1. DAMAGE MAPPING	3
2.1.1. Approach damage mapping	3
2.1.2. Input	3
2.1.2.1. Land use	4
2.1.2.2. Inundation map	5
2.1.3. Damage functions	5
2.1.3.1. Availability damage functions	5
2.1.3.2. Damage function households	7
2.1.3.3. Damage function infrastructure	9
2.1.3.4. Damage function agriculture	10
2.1.3.5. Damage function forest	11
2.1.3.6. Implemented functions and variables	12
2.2. MORTALITY ESTIMATION	13
2.2.1. Input	13
2.2.1.1. Population density	13
2.2.1.2. Inundation map	14
2.2.2. Mortality function	14
2.3. VALIDATION	15
2.3.1. Validation of results	15
2.3.1.1. Total economic damage	15
2.3.1.2. Total fatalities	16
2.3.2. Validation HEC-RAS inundation map	16
2.3.2.1. Spatial comparison	16
2.3.2.2. Qualitative comparison	16
2.3.2.3. Depth line comparison	17
CHAPTER 3. RESULTS	18
3.1. ECONOMIC DAMAGE	18
3.1.1. Damage map	18
3.1.2. Validation damage map	19
3.2. MORTALITY	20
3.2.1. Mortality map	20
3.2.2. Validation mortality map	21
3.3. VALIDATION INUNDATION MAP	21
3.3.1. Spatial comparison	21
3.3.2. Qualitative comparison	22

3.3.3. Depth line comparison	22
CHAPTER 4. CONCLUSIONS	24
4.1. CONCLUSION	24
4.2. DISCUSSION	24
4.3. RECOMMENDATIONS	26
REFERENCES	27
ATTACHMENTS	I
ATTACHMENT A: LITERATURE REVIEW	I
Damage functions	I
Research in the Huong River Basin	III
ATTACHMENT B: APPROACH FOR ECONOMIC DAMAGE MAPPING	V
ATTACHMENT C: MATLAB STRINGS	VII

Chapter 1. Introduction

1.1. General information about Huong River Basin

The Huong River Basin is located in Central Vietnam, bordered on the east by the South Chinese Sea, on the west by the Laos border. The Huong River originates in the mountainous area around the border with Laos and streams in North-Eastern direction to the coast. The Huong River Basin and its adjacent area embrace an area of 3760 km², of which 2960 km² belongs to the main Huong River Basin, and the remaining of 800 km² belongs to contiguous basins (Tran et al, 2007). The Huong River flows into a concatenation of lagoons near Hué, from which it leads to the South Chinese Sea. The Huong River and its lagoons are situated in the Thua Thien Hué Province. Much of this province's infrastructure and industry lies in the coastal plain and most of the population live within 25 km of the coast. This area has a small slope and the Huong River and its tributary streams meander through populated and agriculture area.



Figure 1.1: Location of the Thua Thien Hué Province

The Thua Thien Hué Province has a tropical monsoon climate and is affected by annual tropical storms. These typhoons usually develop in the Northwest Pacific and follow a path over the Philippines, cross the South Chinese Sea and when they land on the Vietnamese coast they loose force, releasing their water over this coastal zone (Vermue, 2006). This causes heavy rainfall up to 1000 mm per day and high wind velocities. Because the Huong River Basin is very flat in the coast area and the basin has no sufficient hydraulic structures to handle this amount of rainfall, the river frequently floods.

In November 1999 disaster floods struck eight provinces in Central Vietnam and the Huong River inundated 90 percent of the lowlands of the Thua Thien Hué Province. This flood lasted for one week, broke five new floodgates and created a new river mouth near the lagoon. Nearly a million homes were damaged of which more than 40 thousand were destroyed. Seven hundred people were killed and the flooding caused 265 million USD of damage plus almost 500 million USD of economic losses. (Reliefweb – Red Cross, 1999)

The November 1999 flood is not the only of its kind. Disasters due to flooding are common in this area and keep causing heavy damage and keep taking lives. Measures against flooding are necessary, but are difficult to implement due to the flat area, the extreme heavy rainfall and the little knowledge about the hydraulic behaviour of the system.

1.2. Preliminary research

To enhance the insight in the hydraulic behaviour of the Huong River, research has been done at the Hanoi University of Science. Vermue (2006) and De Oude (2006) modelled the Huong River Basin in HEC-RAS software and used discharges of the November 1999 flood to simulate this flood and to test some flood drainage measures. This model is updated by Tran Anh Phuong of the Hanoi University of Science and now it is able to provide an inundation map of the Huong River Basin given a certain amount of rainfall as input. However, this inundation map is not validated and therefore not reliable yet.

1.3. Aim of the research

Due to the typhoons that regularly land at the Thua Thien Hué Province of Vietnam, the basin of the Huong River regularly floods. The population and the economy of the province suffer of the consequences of these floods. These consequences exist of economic damage and the fatalities due to flooding. This should be reduced and that is possible in two ways. First, all the effects can be minimized by hydraulic measures that prevent the river of flooding. Second, the consequences can be reduced by increasing the awareness concerning the effect of a flood. A damage map based on the predictions for a flood can be of help in both ways.

In the first way, a damage map gives an overview of the areas that would be heavily damaged in case of a flood. This gives the ability to create insight to the areas that have a high priority for implementing flood prevention measures. In the second way, the local population is given a clarified insight into the dangers that the river brings, so they can prepare themselves and their assets for a flood. The government can use a damage map or its characteristics to focus her attention to the areas that would suffer heavy damages. For this second method, the spread of fatalities due to a flood can also be of use, so besides a damage map a mortality map is to be created.

Finally, an estimate of the accuracy of the results is to be made.

1.4. Research question

This assignment has been done using the inundation depths modelled by HEC-RAS software with the discharge of the November 1999 flood. This information is the foundation to create a damage map and a mortality map for the Huong River Basin. This has been done following the central question stated below. The sub questions have helped to answer the research question.

“How can economic damages and mortality in case of flooding in the Huong River Basin be simulated accurately, based on the HEC-RAS inundation depths?”

1.4.1. Sub questions

- *“Regarding the characteristics of the Huong River Basin, how can a function for economic damage be described?”*
- *“Regarding the characteristics of the Huong River Basin, what concepts for mortality can be used?”*
- *“How can the reliability of the economic damage model and mortality model be estimated based on the reliability of their inputs?”*

In chapter 2, the methodology to answer these sub questions is explained. In chapter 3 the results are documented and in chapter 4 conclusions from these results are drawn and discussed.

Chapter 2. Methodology

To answer the research question, the sub questions will be answered in their stated sequence in the next three sections. This implies that this assignment first will implement a damage mapping method and search for a mortality concept, then these results and the HEC-RAS inundation depths are verified.

2.1. Damage mapping

- “Regarding the characteristics of the Huong River Basin, how can a function for economic damage be described?”

2.1.1. Approach damage mapping

Damage mapping of flood risk areas is of great value for the decision-making concerning vulnerable areas, and therefore it is already done by many governments and scientists. This causes a large amount of available literature about damage mapping, see Attachment A: *Literature Review*. The useful literature is selected and this provided an approach for the damage assignment, see Attachment B: *Approach economic damage*. This resulted in the approach as stated in table 2.1. The damage mapping itself is documented in part 2.1 *Damage mapping*. The results are described in chapter 3.

Steps of approach damage mapping:	... implemented in this assignment with:	Documented in:
Determination of considered damage categories	- Residential area (urban and rural) - Infrastructure (roads and railways) - Agriculture (rice and other crops) - Forest area	Part 2.1.2. <i>Input</i>
Determination of inundation characteristics	Inundation depth (observed and predicted)	
Collection of land use data	Mixture of data of Thua Thien Hué Province and Hanoi University of Science. Merged to Matlab matrices with 90 meter grid.	Attachment C: <i>Matlab strings</i>
Determination of values of assets	- Maximum damage values per square meter, per land use type - Preliminary research in published articles	Part 2.1.3. <i>Damage functions</i>
Determination of damage functions	Different depth-damage functions, each adapted to one land use type.	
Damage calculation and presentation	Damage is calculated for each grid cell. Available data will be converted into Matlab matrices, to calculate the damage and map it in ArcView with the spatial data of the resource data.	Part 3.1. <i>Damage Map</i>

Table 2.1: Damage assignment approach in this document

2.1.2. Input

Economic damage due to flooding depends on many factors, divided into two parts. One part is the collection of characteristics of the damaged assets that are of influence. Second part is the collections of characteristics of the flood itself that exert influences. The most reliable result would be obtained if as much as characteristics would be taken into account. However, this assignment depends on the available data. For the characteristics of the damaged assets the spatial data of some land uses are at hand. The characteristics of the flood in this assignment are defined by the output of the HEC-RAS model and exist of an inundation map based on the discharge of the November 1999 flood. (see part 1.2. *Preliminary research*)

2.1.2.1. Land use

The land use data is obtained by the Hanoi University of Science from the government of the Thua Thien Hué Province. The data covers the whole province, but only the data of the flooded area is displayed, since the data outside the flooded area is not necessary to use. The data has been converted to ESRI files to view the data in ArcView software and to convert it to ASCII-files with a 90 meter grid. In figure 2.1, the map is displayed with all the land uses that are used for the damage mapping. The location of the left lower corner of the land use figure is longitude: 758.628.434 and latitude: 1.804.480.528. The total distance between the top and the bottom of the figure is 38,9 km.

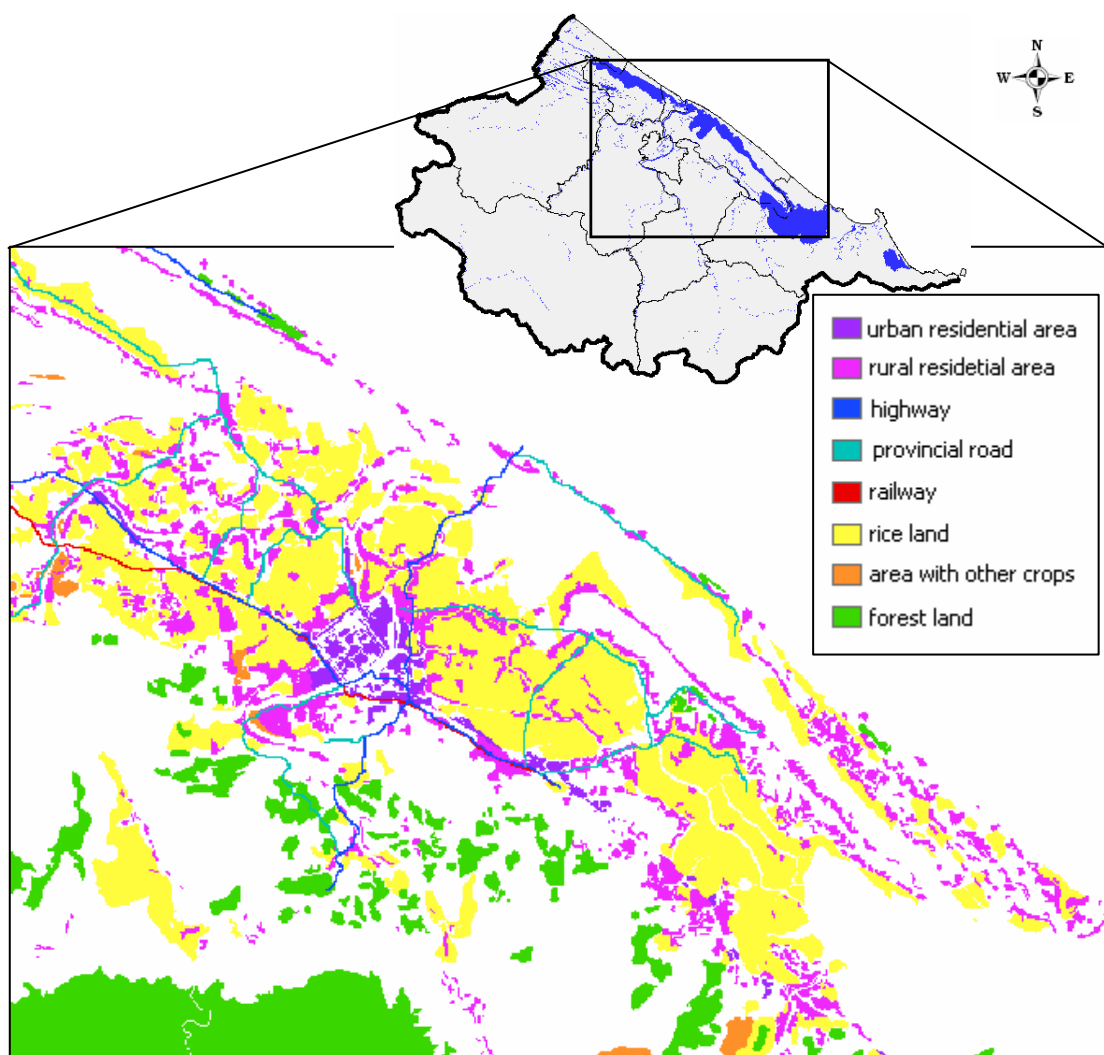


Figure 2.1: Available land use data in the Thua Thien Hué Province

The urban residential area has a bigger concentration of buildings and its buildings have more levels than the rural area. The urban area is mostly located in Hué City, that in figure 2.1 can be recognized by the square shape of the channels around old Hué Citadel. Other urban area is located at the Bo River in the North West of the figure, near the highway. The rural area is mostly located near the riverside and around the lagoons. It is surrounded by rice land that can be found in the whole flat area of the Thua Thien Hué Province. The forest land is located more uphill. The area that is defined 'with other crops' is the land used for agriculture that is not rice. Because not many other crops are grown in the flooded area, these are not defined in more detail. The railroad and highway 1A run from the North West to the South East. These roads are not drawn in the figure from the moment that they leave the urban area, due to lack of data.

2.1.2.2. Inundation map

The inundation depth map created by the HEC-RAS model of the Huong River Basin provides the inundation for a certain amount of rainfall. The inundation map that will be used in this assignment to create the damage map is based on the precipitation during the November 1999 flood. In figure 2.2, the spatial data of these inundation depths is drawn, in figure 2.3 this data is drawn with the land use types in the background.

Both figures have the same location of the left lower corner as figure 2.1, an equal grid size and a length from top till bottom that is similar to figure 2.1.

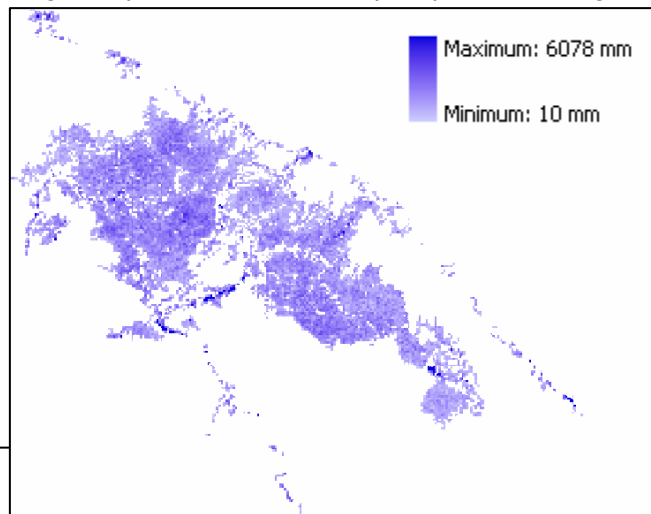


Figure 2.2:
Inundation map
(HEC-RAS model)

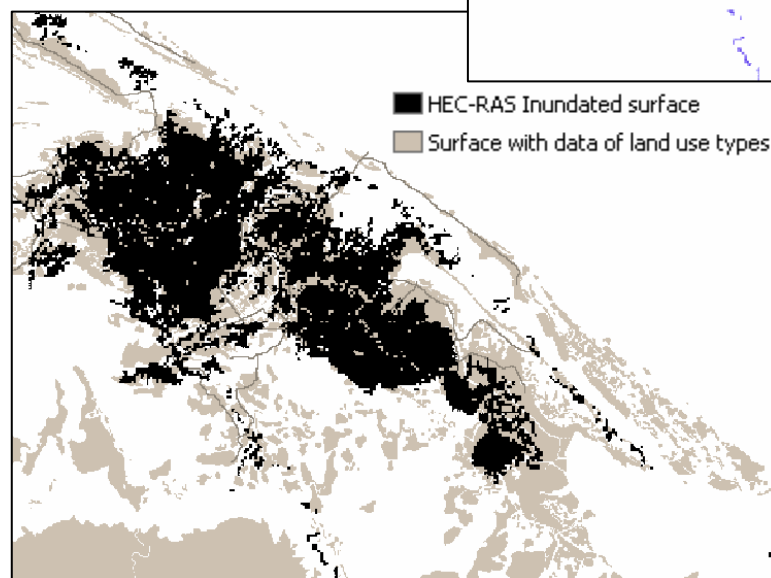


Figure 2.3: Overlay:
Inundation map in black
with land use in
background

2.1.3. Damage functions

Since only the inundation depth and a collection of land use types are available, a damage function should be applied with these two characteristics as input. In this section, first the available damage functions for this damage assignment are determined. Then the used damage function will be described per land use type, including the dept-damage curves and the maximum damage values.

2.1.3.1. Availability damage functions

Many relative depth-damage functions exist in the literature to calculate the economic damage (ED , in USD/m^2). This type of function is based on a the damage factor (α , no dimension) derived from a depth-damage curve dependent on the inundation depth in meters, multiplied by a maximum damage value (D_{max} , in USD/m^2). The depth-damage curve and the maximum damage value are both determined per land use type. The depth-damage curve represents the vulnerability of a concerning object or asset when it is flooded, by a relation between inundation depth and the resulting damage as a fraction of the maximum damage. This maximum damage value is identified by the loss value in case the object or asset is fully flooded.

Depth-damage function: $ED = \alpha(d) \cdot D_{max}$

Because the depth-damage curve and the maximum damage value depend strongly on the characteristics of the object or asset, a damage function should not be simply taken over from a preliminary research. The characteristics of the objects and assets in the Huong River Basin differ from the characteristics in these researches. Therefore, the most effective method to retain relatively accurate damage functions is to look for damage assignments that have been done in the Vietnam area. Whenever these damage functions do not exist for certain types of land uses, it is not possible to create this function due to lack of time and knowledge. In this case, a damage function from preliminary research will have to be used, taken into account the consequence that the function may not fit the subject and the result is not accurate.

Available depth-damage curves

Considering the depth-damage curves that are developed for assignments in the Vietnam area, De Bruijn (2005) is a useful resource. Since this research only concerns agriculture, and infrastructure, more damage curves are needed for the other land use types. As presented in the Literature Review (see Attachment A), no other depth-damage curves have been developed for Vietnamese areas. Only the depth-damage curves of the thesis of Huang (2005) and the Standard Method of Kok et al. (2005) are available from the acknowledged research. The Standard Method is developed in The Netherlands for Dutch applications, the curves of Huang are for an area near the German river Elbe. Further on, only for the Standard Method the foundations of the maximum damage value are known. For that reason the damage curve of Kok et al. is used rather than the damage curve of Huang. In table 2.2 the available damage curves are presented per land use this assignment has available. The bold crosses mark the damage curves that will be used in this assignment.

	Households	Agriculture	Forest area	Infrastructure
De Bruijn (2005)		x		x
Kok et al. (2005)	x	x		x
Huang (2005)	x	x	x	x

Table 2.2: Available depth damage curves per land use

Available maximum damage values

The applied maximum damage value exerts the greatest influence on the accuracy of the damage function. Also, this value will be very different in the Vietnamese situation compared to the western situation for which the damage function is developed. So it is important that the applied maximum damage values are taken from local damage assignments or Vietnamese databases. It would be even more accurate when the maximum damage value is linked to a depth-damage curve in the same assignment. Then the combination is reliable to use in this assignment. If such data is not available for a land use, it is to be reconstructed using the definition for the maximum damage value of Kok et al. (2005). In table 2.3 the resources of the maximum damage values are listed.

	Maximum damage value reconstruction
Objects	Rebuild costs
Assets	Replacement value
Harvest, stock	Market value
Direct damage production loss:	Added value
Indirect damage production loss:	Added value from surroundings of flooded area

Table 2.3: Reconstruction of maximum damage value, per subject (Kok et al, 2005)

De Bruijn (2005) provides for the agriculture and infrastructure depth-damage curves with the

corresponding maximum damage values for the Mekong Delta, Vietnam. All this data will be used because it is very useable for this assignment. Concerning forest area, only the data of CRUEIP (2003) is available. This data concerns the replacement rates for six towns in Central Vietnam. Gupta et al (2004) did an assignment in an area nearby the Huong River, but for the households and the rice paddy she provides only the average damage, which is useless considering the definition of Kok et al of the maximum damage value. Gupta et al do provide the rebuild costs for the road, but this significance is overtopped by De Bruijn. In table 2.4 the bold crosses mark the maximum damage values that will be used in this assignment.

	Households	Rice field	Forest area	Highways	Provincial roads	Railways
De Bruijn (2005), maximum damages values (*m ⁻² / **m ⁻¹)		x*		x**	x**	x**
CRUEIP (2003), replacement values (m ⁻²)	x	x	x			
VDP (2004), average value (32 m ⁻²)	x					
AUDMP (2001) average construction cost (49 m ⁻²)	x					
Gupta et al (2004), *average damage / **construction costs	x*	x*			x**	

Table 2.4: Damage values per land use, per resource

For the households various data is available. Vietnam Disaster Prevention (VDP, 2004) provides the average house value in a few communities in the Thua Thien Province, based on a field study. The document of the Asian Urban Disaster Mitigation Program (AUDMP, 2001) provides the average construction costs in the Thua Thien Hué Province, based on the study of Disaster Workshop France. Unfortunately, the original data of this study is not obtained.

2.1.3.2. Damage function households

Damage curve

Kok et al. (2005) have developed damage curves for houses. He makes a difference between low-rise buildings (two main floors), middle-rise buildings (four main floors) and high-rise buildings (six main floors). A visit to the city of Hué and its surroundings made clear that the urban residential area nowadays includes mostly four level buildings, while in the rural residential area houses with one or two main floors are common. So for the urban residential area the middle-rise building curve will be used and for the rural residential area the low-rise building curve will be used as the depth-damage curve. The used curves are shown in figure 2.11. Using these curves, two assumptions have been made that need some explanation.



Figure 2.4: Houses in the urban area of Hué

First, an assumption is made concerning the proportion of the damage of the building to the loss of the assets within the building. The Standard Method uses the Dutch proportion to

develop the curve. These circumstances can be different in Vietnam, but this assignment assumes that this damage proportion is similar. Second, in the Standard Method the depth-damage curves come with a critical water speed that affect the damage factor. When inundation comes together with water speeds above this critical point, buildings can collapse and the damage factor will be 1,0. The water speeds for the Huong River Basin are not known, so the depth-damage curves that are used and displayed are not affected by the water speeds.

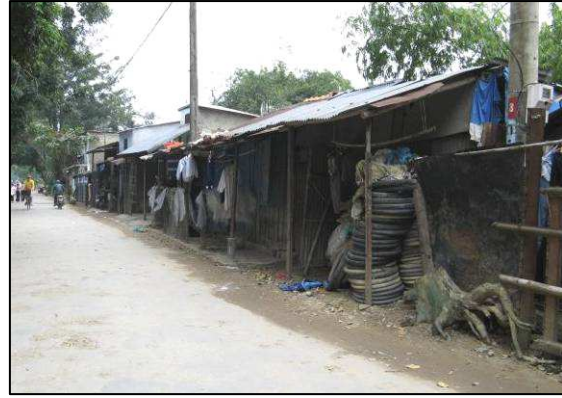


Figure 2.5: Houses in the rural area around Hué

Extra factors

The used curves for the damage factor are based on the sum of the direct damage, the direct damage due to production loss and the indirect damage. Since these aspects overlap, the Standard Method applies a reduction factor of 0,75 (Kok et al, 2005). This factor (γ) will also be implemented in this assignment.

In figures 2.6 and 2.7 it becomes clear that the area for urban residents and rural residents is not completely covered with buildings. A factor (β) is used to correct this information. 40% will be used for the urban residential area, 20% will be used for the rural residential area.

These two factors are implemented by using the following function, in which ED is the economic damage in USD/m², α is the damage factor for the households that is dependent on the inundation depth in meters (d), D_{max} is the maximum damage for households in USD/m², γ is the reduction factor and β is the surface factor.

Economic damage for households: $ED_{Households} = \alpha(d) \cdot D_{max} \cdot \gamma_{Reductionfactor} \cdot \beta_{Surfacefactor}$

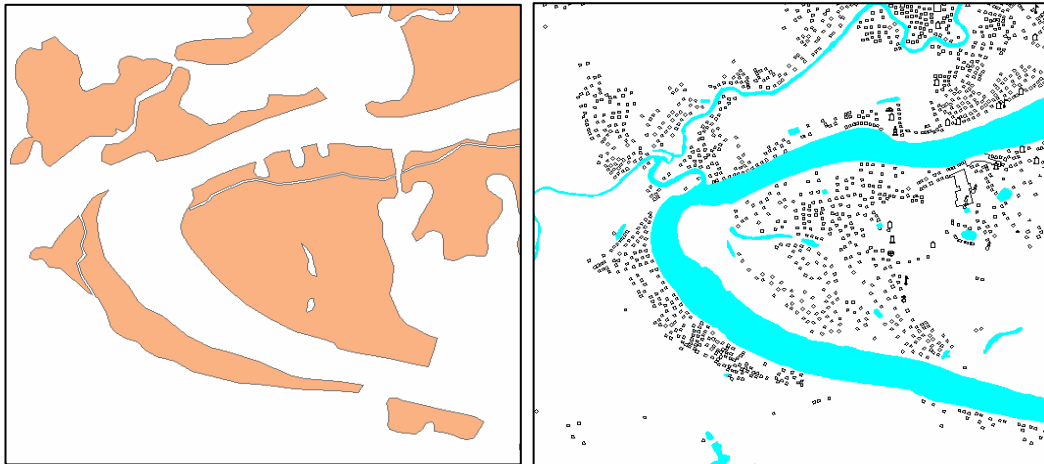


Figure 2.6: An estimation of 20% is used for the coverage of houses in the rural residential area.

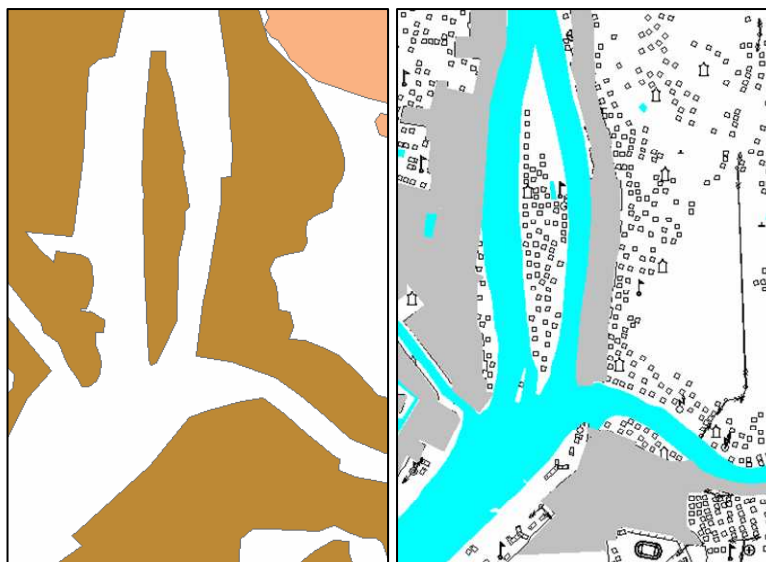
L: the pink surface is used rural residential area. R: the dots represent the actual rural houses.

Scale: Total width of 1 picture is 3,8 km.

Figure 2.7: An estimation of 40% is used for the coverage of houses in the urban residential area.

L: the brown surface is used urban residential area. **R:** the dots represent the actual urban houses, the grey area is totally covered with houses.

Scale: Total width of 1 picture is 1,8 km.



Maximum damage value

Since the damage curve of the Standard Method of Kok et al. (2005) is used, the maximum damage value can be developed with the foundations used in this Standard Method. As shown in table 2.1, the maximum damage values for a household are based on the rebuild costs for objects and the replacement value for the assets inside the house.

Table 2.4 shows the four available resources for the necessary data. According to VDP (2004), the house value is 28 USD/m² (for an average surface of 32 m²). According to the database of AUDMP (2001), the construction costs (for an average surface of 49 m² per building) are 16 USD/m². So the house value of VDP is 175 % times the construction costs of AUDMP. This implies that the VDP calculated an house value that is based on construction costs plus the assets in the house. The amount of 28 USD/m² is similar to the replacement value of 29 USD/m² that CRUEIP (2003) rates for stone houses that are build to last up to 20 years. This type of houses is most common in the urban area of the Thua Thien Province. In the rural area, wooden houses with a shorter life estimation are more common, which CRUEIP values at 22 USD/m². So a value of 29 USD/m² should include the damage value of a house with its assets and is used as maximum damage value for houses in the urban residential area. For the rural residential area the value of 22 USD/m² is used as maximum damage value.

2.1.3.3. Damage function infrastructure

Damage curve

In the thesis of De Bruijn (2005), a damage curve is developed for roads and railways in the Mekong Delta. This curve is similar for different types of roads, and the variety of the maximum damage values distinguishes the highways, provincial roads and railroads. The damage to rural roads is neglected since no maximum damage value for this type of road is known.

Extra factor

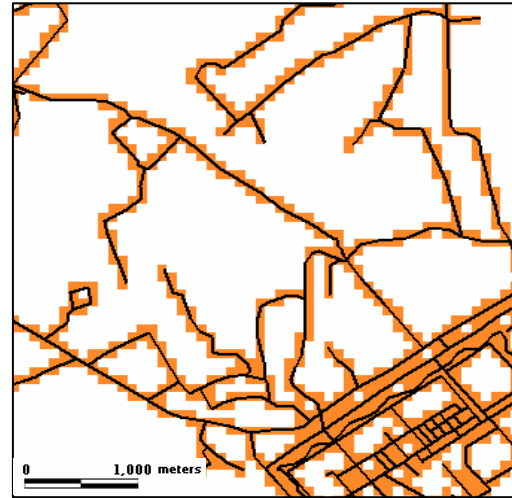
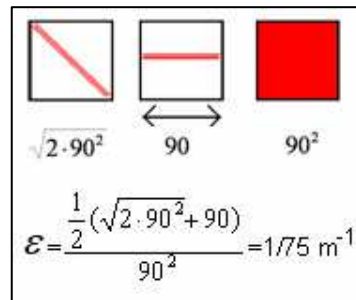
The resource data of the infrastructure exists in polylines that represent the lengths of the roads. During the conversion into the Matlab matrices, these polylines are converted into cells because the damage function needs its input in square meter. A conversion factor is used to correct the conversion from a USD/m unit into a USD/m² unit. This factor is calculated using

the average length of a road through a cell, and the surface of this cell. The formula for this factor (ε) is provided in figure 2.8. The factor is implemented in the following damage function, in which ED is the economic damage in USD/m², α is the damage factor for infrastructure depending on the inundation depth d , $D_{\max}$ is the maximum damage for the specific infrastructure (in USD/m²) and ε is the conversion factor.

Damage function for infrastructure:

$$ED_{Infrastructure} = \alpha(d) \cdot D_{\max} \cdot \varepsilon$$

figures 2.8 & 2.9:
Calculation of
surface factor and
infrastructure
cells. The length
of one cell is 90
meter.



In figure 2.9 the resource data in polylines is printed in black, the cells used for Matlab are printed orange. This is an example of the smaller roads in the Northwest area of Hué City. The cells that are converted into ASCII-files have a width of 90 meters. The cells have a surface of 90² m². With these variables the conversion factor that is to be used, is 1/75 m⁻¹. This factor will be applied to all the infrastructure land uses.

Maximum damage value

The maximum damage values that are used in the thesis of De Bruijn, do not need to be adapted because they are developed for a Vietnamese situation. Only the variable market-value can have an effect to the maximum damage value, that is not taken into account in this assignment. The maximum damage value of the provincial road is 80 USD/m, the maximum damage value of the national road is 400 USD/m and for the railway the maximum damage value is 1000 USD/m.

2.1.3.4. Damage function agriculture

Damage curve

In Vietnam, many types of rice farming systems and rice varieties are used, depending on soil type, elevation, flood frequency, flood depth and flood duration. The varieties in Vietnam can be categorized into three main groups: Wet season rainfed rice, wet season deep water rice and dry season recession rice. The dry season recession rice is manually inundated on a regular base, but not always (like deep water rice) or never (like rainfed rice). De Bruijn (2005) developed three damage curves for the mentioned rice types in the Mekong Delta. In the rice land of the Huong River Basin mainly the dry season recession rice is cultivated, therefore the damage curve for this rice type is used. It is assumed that all the rice land in this area is of the same rice type, so the damage curve (plot in figure 2.11) will be used for the whole area.

Other crops are scarce in the inundated area and therefore these are less significant. Although, the location data for this land use is available so this land use will be taken into account. The damage curve for rainfed rice of De Bruijn will be used for the other crops in the Huong River Basin, as shown in figure 2.11. It is assumed that the other crops have the same

damage characteristics as the rainfed rice, since De Bruijn uses this damage curve also for other crops in the Mekong Delta in her own assignment.



Figure 2.10: A recession rice field in the end of the wet season.

Maximum damage value

The depth-damage curves that Bruijn made for the agriculture in the Mekong Delta, come with maximum damage values for the particular crops. For the dry season recession rice she uses a maximum damage value of 440 USD per hectare, for the other crops than rice she uses a maximum damage value of 200 USD per hectare. These values are implemented in this assignment and are shown in table 2.5.

2.1.3.5. Damage function forest

Damage curve

Since only one depth-damage curve is available in the literature for the forest area (see table 2.4), this curve will be used in this assignment. The thesis of Huang (2005) provides the damage curve as shown in figure 2.11.

Maximum damage value

To develop a suitable maximum damage value for the damage function of forest land, the value is reconstructed with the information in table 2.3. Since the report of CRUEIP (2003) provides the replacement value for forest area in the Thua Thien Hué Province, this seems like a reliable value. CRUEIP determines the replacement value for private land that contains forest at 0,84 USD per square meter, this value is added to table 2.5.

2.1.3.6. Implemented functions and variables

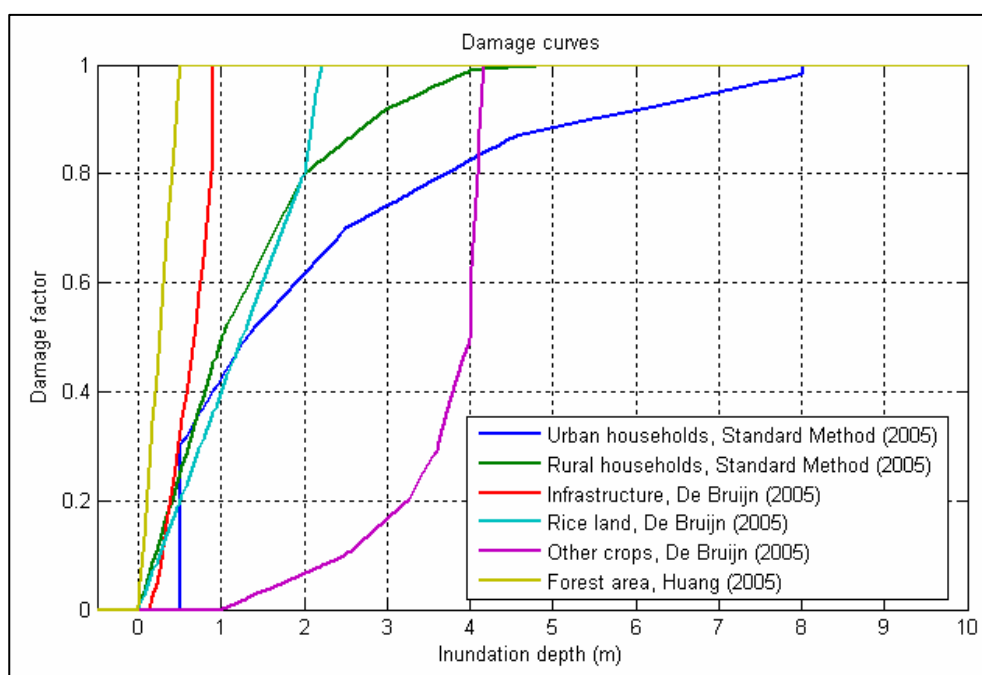


Figure 2.11: Used depth-damage curves

	Used maximum damage value	Resource characteristic	Extra factors
Urban area	29 USD/m ²	Construction costs & Asset value	Surface factor: 0.4 Reduction factor 0.75
Rural area	22 USD/m ²	Construction costs & Asset value	Surface factor: 0.2 Reduction factor 0.75
Provincial road	80 USD/m	Construction costs	Conversion factor: 1/75
National road	400 USD/m	Construction costs	Conversion factor: 1/75
Railway	1000 USD/m	Construction costs	Conversion factor: 1/75
Rice	0,044 USD/m ²	Maximum damage value	
Other crops	0,02 USD/ m ²	Maximum damage value	
Forest	0,84 USD/m ²	Replacement value	

Table 2.5: Used maximum values and the extra factors per land use

2.2. Mortality estimation

- “Regarding the characteristics of the Huong River Basin, what concepts for mortality can be used?”

Mortality is dependent of many variables, like evacuation time, evacuation possibilities, water rising speed, water depth, velocity of the water and average repetition time of the flood. For the Huong River Basin the only available information for calculating the number of casualties, is the spatial data of the water depth and of the density of the population. Concepts for simulating the number of fatalities over the area have been searched, that have the inundation depth and the density of the population as input. The only article containing a depth-mortality curve is an article of Jonkman & Asselman (s.a).

Jonkman & Asselman (s.a.) derived depth-mortality curves from the information on the 1953 flood in The Netherlands. This function is not verified on its validity for the Huong River Basin, but may give an indication about the casualties due to a flooding. When this depth-mortality curve is applied to the November 1999 flood data of the Huong River Basin, the number of total simulated casualties can be validated with the total amount of fatalities due to that particular flood.

2.2.1. Input

2.2.1.1. Population density

The data of the population density is obtained from the government of the Thua Thien Hué Province. It consists of the total amount of residents per district, together with the surface of the district. This results in the average density of the population per district. The data has been converted to ESRI files to view the data in ArcView software and in order to convert it to ASCII-files with a 90 meter grid. Figure 2.12 shows the grid data with the location of the left lower corner of longitude: 758.628.434 and latitude: 1.804.480.528. The total distance between the top and the bottom of the figure is 38,9 km.

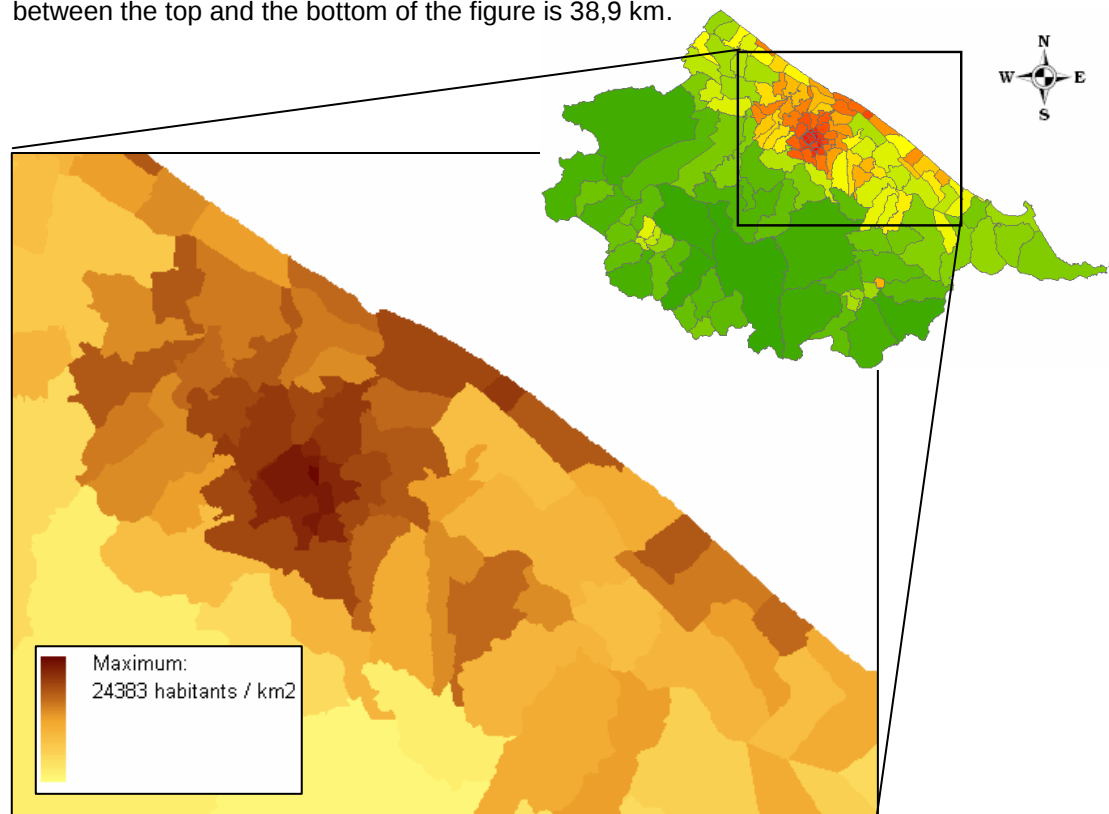


Figure 2.12: Population density in the Thua Thien Hué Province

2.2.1.2. Inundation map

The inundation depth map used for the mortality function (figure 2.13) is the same map used for the damage function (figure 2.2). In figure 2.14, the inundation map is displayed with the population density map in the background.

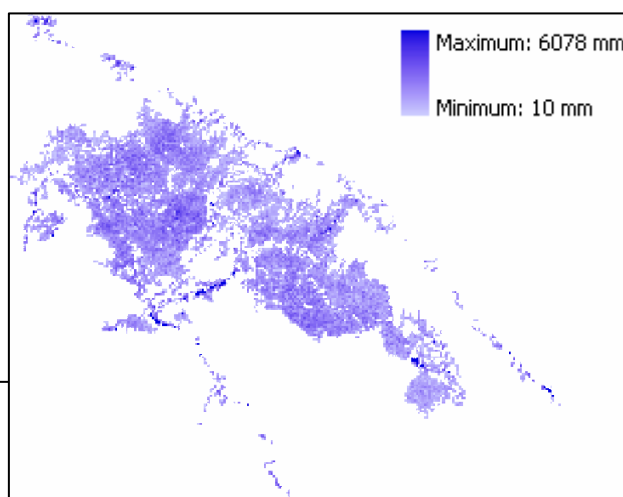


Figure 2.13:
Inundation map
(HEC-RAS model)

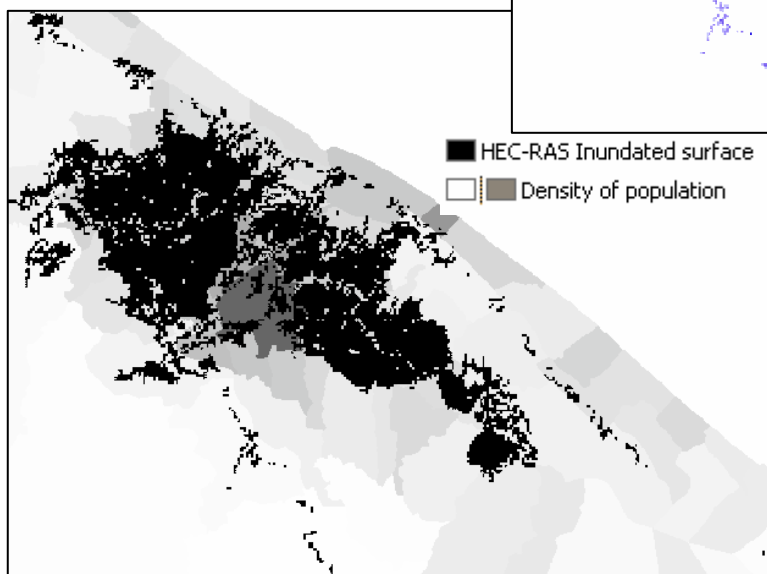


Figure 2.14: Overlay:
Inundation map in black with
density of population in
background

2.2.2. Mortality function

Jonkman & Asselman have developed two types of depth-mortality curves. The first is for the fatalities due to drowning if the local rate of the water rising exceeds 1 m/hr (fast rising curve). The second is for fatalities caused by water that rises slower than 1 m/hr (slow rising curve). So the two curves are derived from two data sets, distinguished by the water rising speed. The fatalities of the first data set are presumed to be drowned due to the high water depth and the second data set represent other causes of death such as hypothermia, fatigue of person or indirect causes like electrocution or heart attack. Since the rising speed of the water is not known, both the curves will be applied next to each other.

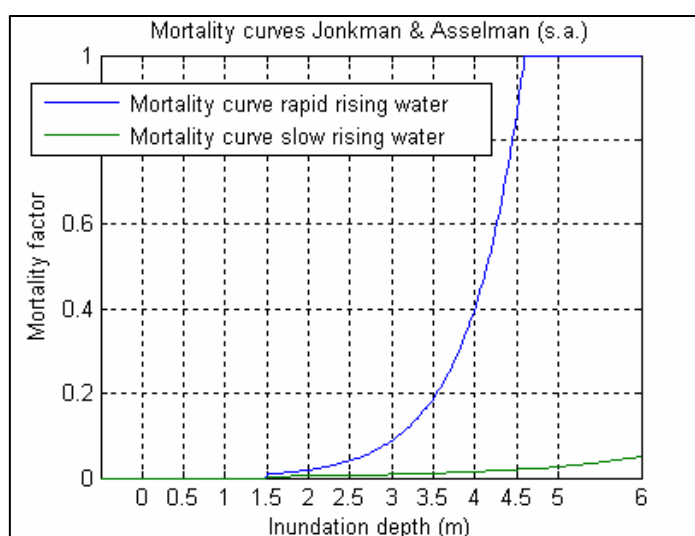


Figure 2.15: Slow rising and Rapid rising depth-
mortality curves of Jonkman & Asselman

Jonkman & Asselman state that deaths due to high flow velocities will occur if the water depth- flow velocity product exceeds $7\text{m}^2/\text{s}$ and if the flow velocity is larger than 2 m/s . This is neglected in this assignment since only the water depth is available.

The fast rising curve and the slow rising curve for the mortality factor (f) are stated below and drawn in figure 2.15. In these functions, d is the inundation depth.

$$f(d)_{\text{fast}} = 9,18 \cdot 10^{-4} \cdot e^{1,52 \cdot d}$$

$$f(d)_{\text{slow}} = 1,41 \cdot 10^{-3} \cdot e^{0,59 \cdot d}$$

This factor f is implemented with the next function, with n for the number of habitants per grid cell and M for the number of fatalities per cell.

$$M = f(d) \cdot n$$

2.3. Validation

- “How can the reliability of the economic damage model and mortality model be estimated based on the reliability of their inputs?”

The reliability of the economic damage model and of the mortality model can be estimated by a validation of its inputs and its outputs. The models have several aspects, of which an overview is made in table 2.6. An aspect is capable for validation if true data is available for a situation that the model is based on. The models in this assignment are based on the measured discharges of the November 1999 flood, so the validation is dependent on the information about the economic damage and mortality of that particular flood. Since an inundation map of this flood and some data about the total damages and fatalities is known, a validation can be done for the aspects that are printed bold in table 2.6.

	Aspects	Validation
Damage model	HEC-RAS Inundation depths	Inundation map of the November 1999 flooding
	Land use	-
	Damage function	-
	Result	Total amount of damage during the November 1999 flooding
Mortality model	HEC-RAS Inundation depths	Inundation map of the November 1999 flooding
	Population density	-
	Mortality function	-
	Result	Total number of fatalities during the November 1999 flooding

Table 2.6: Aspects of assignment that can be validated marked bold

Since the inundation maps that the two models use are similar, in total three validations will be implemented. The validation of the inundation map can be more extensive than the results of the two models, since the known data used for the validation of the two models only concern the total damage and total fatalities.

2.3.1. Validation of results

2.3.1.1. Total economic damage

The data about the damage due to the November 1999 flood has no spatial information and is not separated into the categories of land use types, which this assignment applies.

Therefore, the only validation of the result of the damage model is by comparing its accumulated damage with the accumulated damage of the November 1999 flood.

2.3.1.2. Total fatalities

For the validation of the mortality map, similar considerations hold as for the validation of the economic damage. The possible validation exists only of comparison of the total amount of fatalities with the reported casualties during the November 1999 flood.

2.3.2. Validation HEC-RAS inundation map

For the validation of the HEC-RAS inundation map, three methods are used. First, the location of the inundation data is compared with an inundation map that contains observed data. Second, the inundation data for the whole map is qualitative compared with the observed data. Finally, the HEC-RAS depths are compared with the observed data over one cross-cut line in the inundated area.

The inundation map that contains observed data is drawn in figure 2.16. Some data is lacking, this can be recognized by the abrupt boundaries in this map. Further on, the data is only determined in three categories of 1 meter water depth and one category for everything more than three meter water depth. In order to compare the inundation map of the HEC-RAS model with this map, the categories of this map are labelled with these inundation depths:

0-1 meter is 50 cm
1-2 meter is 150 cm
2-3 meter is 250 cm
>3 meter is 400 cm.

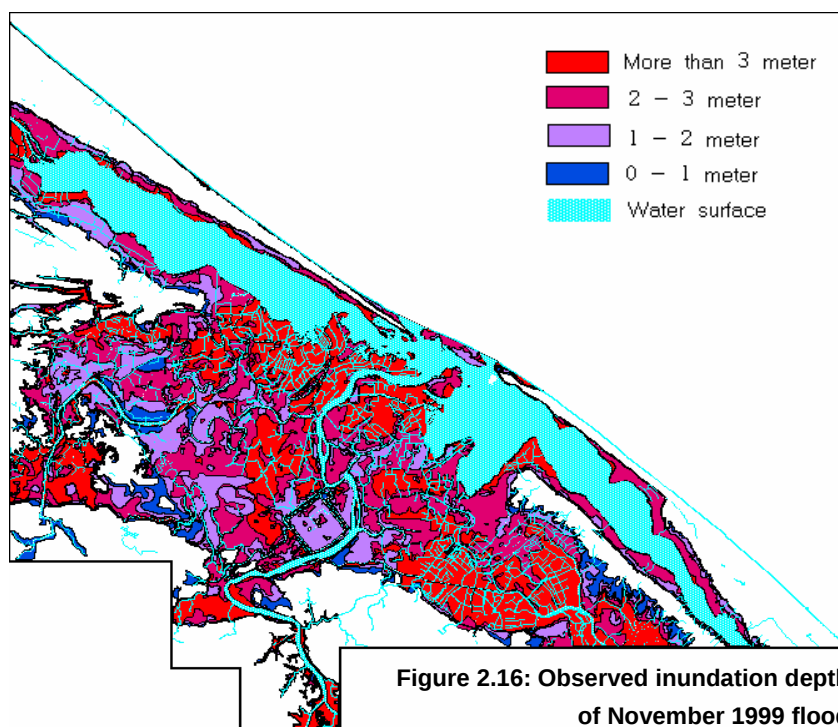


Figure 2.16: Observed inundation depth of November 1999 flood

2.3.2.1. Spatial comparison

The location of the inundated area according to the HEC-RAS model, is compared with the location according to the observed inundation map. The total surface of the observed map is calculated and compared with the total surface of the HEC-RAS inundation map. The surface that is in both maps inundated are pointed out, as well as the inundated surface according to the HEC-RAS model that is not inundated according to the observed data. This information is described in proportion to the total surface of the observed inundated area.

2.3.2.2. Qualitative comparison

Next to the spatial comparison, it is interesting to see the actual similarities of the HEC-RAS

inundation map and the observed inundation map. To compare these maps, the HEC-RAS inundation map is adjusted to the categories of the observed map. The real inundation map is sliced into four categories of inundation depth, so this is also done for the HEC-RAS map. Using Matlab strings (see Attachment C), the percentage of the correct data in the HEC-RAS inundation map can be derived and the data can be drawn into a map.

2.3.2.3. Depth line comparison

When the depth of the map is drawn into a cross-cut, an impression of the differences between the inundations can be obtained. The line has to cut interesting areas of the map, so multiple categories of the real map and if possible the minimum depth and maximum depth of the HEC-RAS inundation map.

Two lines have been selected to make the depth line comparison, they are drawn in figure 2.17. The most interesting locations to validate are selected by its maximum and minimum depths and the areas in between. Some heavily inundated areas, recognized by its large surface of maximum inundation, are located in the South West of the map, North of the Hué City and South East of the Hué City. Further on, the high grounds in the middle of the inundated area are of interest. The two lines drawn from North to South and from West to East cover as much of these areas as possible.

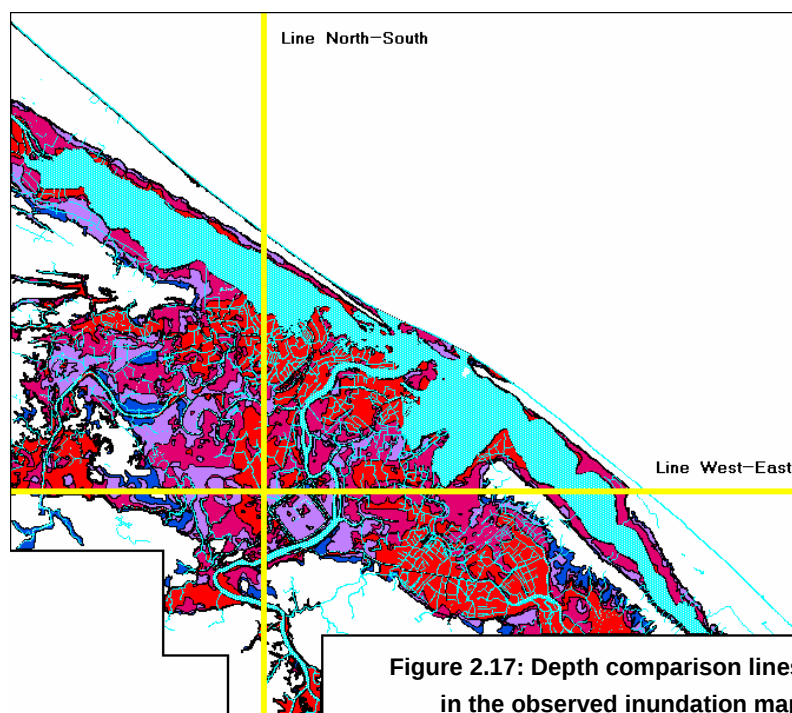


Figure 2.17: Depth comparison lines in the observed inundation map

Chapter 3. Results

3.1. Economic damage

3.1.1. Damage map

The damage map that is obtained for the Huong River Basin is showed in figure 3.1. The data is drawn in the cells of 90 by 90 meters. The total width of this area is 58,3 km, the height is this map is 39,1 km and the lower left corner is located at longitude 759.530.190 and latitude 1811.030.205.

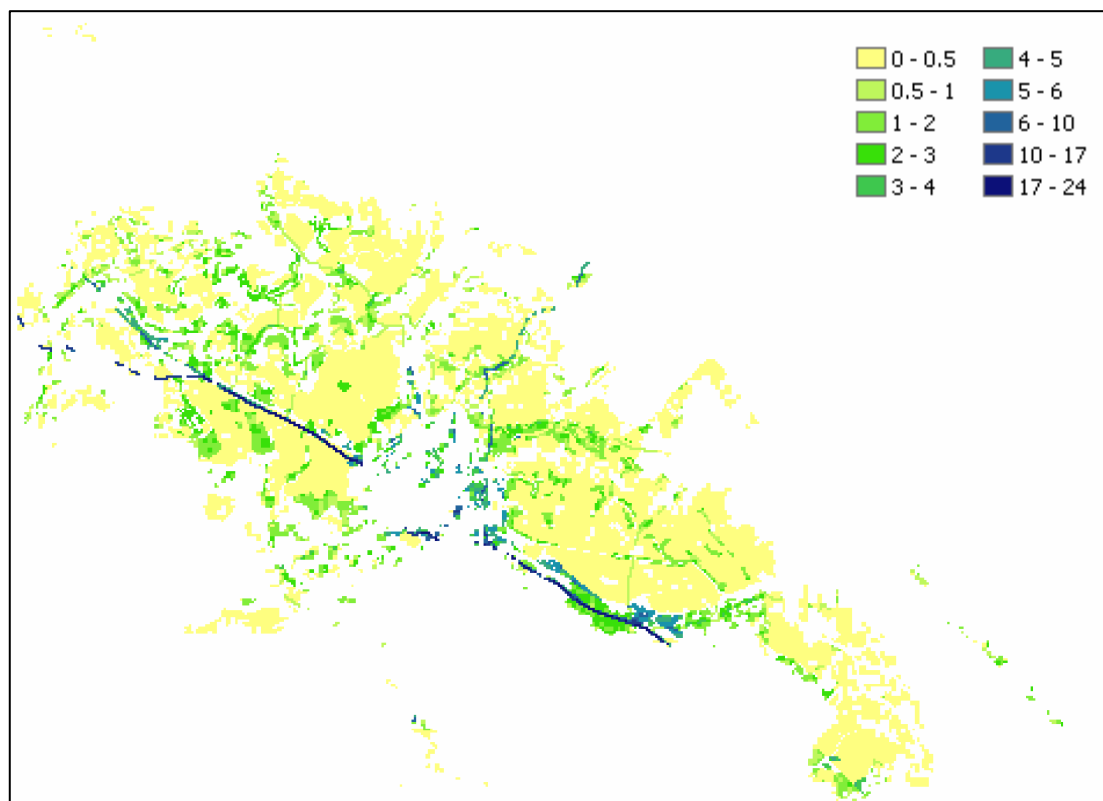


Figure 3.1: Damage map in USD/m², using the HEC-RAS inundation depths

The accumulated damage in this damage map is 207 million USD. As presented in Chapter 2 “Methodology”, this value is based on a limited amount of land use types and the inundation depths of the HEC-RAS model using the discharge of the November 1999 flood. The spatial damage data in figure 3.1 shows that the damage per square meter is most large in the area with infrastructure. Remarkable is that in Hué City are some locations with a prediction of expensive damages, but in general the city suffers only of a few damages overall. This probably is caused by the smaller inundation depth due to the conventional irrigating system around the old Citadel of Hué. Outside Hué, the rural areas are exposed to damage until 4 USD/m² and the rice fields have only damage below 0,5 USD/m².

Taking into account the medium damages per square meter of the rural area and its large surface, this land use type exerts a very large influence on the total predicted damage in the Huong River Basin. The rural area covers the second largest surface in the inundated region and is subject to 53 percent of the total damage. In figure 3.2 all the inundated surfaces and damages are determined per land use type. After the rural land use, the railways and the urban areas are the next land use types that suffer of large damages. The damage to the forest area and to the area with other crops is marginal, the damage to the rice fields is in proportion to its inundated surface also negligible. In table 3.1 the average damage per land use type is calculated and compared with the used maximum damage. This shows that the

rice land, the forest area and area with other crops have average damages most close to its maximum damage values. After these land use types, the rural and urban areas have the highest damages in comparison to its maximum damage values.

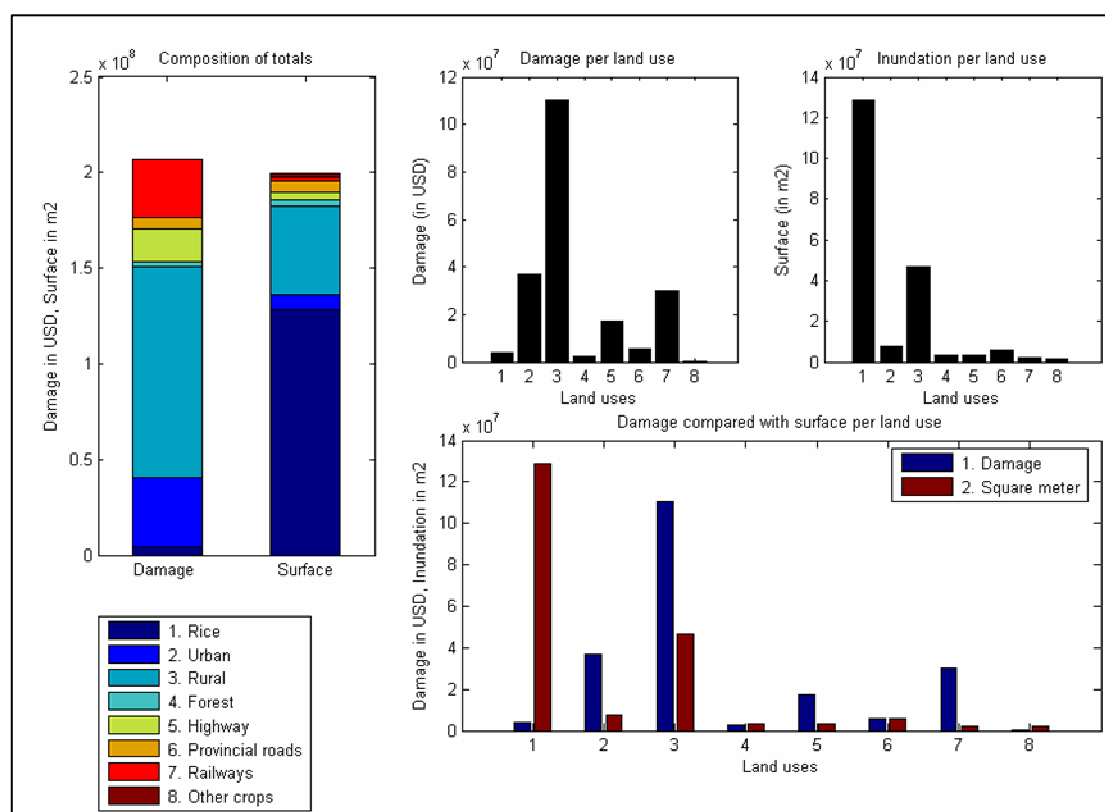


Figure 3.2: Damages and inundation surfaces per land use

	Average damage	Maximum damage value	Percentage
Rice	0,0403	0,044	92
Urban	5,53	29	19
Rural	2,67	22	12
Forest	0,84	0,84	100
Highway	5,05	400	1,2
Provincial roads	1,05	80	13
Railways	12,2	1000	1,2
Other crops	0,0053	0,02	27

Table 3.1: Average calculated damage and maximum damage value per land use

3.1.2. Validation damage map

To validate the damage map model without the dependency on the accuracy of the HEC-RAS model, also the total damage that are caused in case of the observed inundation depths will be used. The total damage with the HEC-RAS model input is 207 million USD, with the observed inundation map the total damage due to this damage map is calculated to 285 million. Comparing these numbers with the damage of the November 1999 flood that is reported by international resources (Reliefweb – Red Cross & USAID, 1999), the total amount of damage according to the damage map model seems to be quite accurate (see table 3.2).

Damage reported by international organisations (in units)		Damage calculated (in USD)		
Homes damaged	870.000	Based on:	HEC-RAS inundation depths	Observed inundation depths
Homes destroyed	41.846			
Classrooms destroyed	94.000	Urban area	36.679.000	66.589.000
Clinics damaged	510	Rural area	110.220.000	154.590.000
Hectares inundated rice fields	66.308	Rice fields	4.096.000	6.383.800
Hectares inundated farmland	30.700	Forest area	2.633.400	2.612.700
Megaton of food lost	205.000	Highway	17.207.000	20.627.000
Hectares fish farms destroyed	3.117	Railroads	30.227.000	23.535.000
Cattle killed	25.000	Provincial roads	5.746.100	10.859.000
Boats and ships damaged	1.162	Other Crops	5.143	15.525
Estimated damage	265 million	Total damage:	207 million	285 million
Estimated economic losses	488 million			

Table 3.2: Total calculated damage (using two different inputs) and reported damages in USD

In the comparison of table 3.2, the reported economic losses should not be taken into account because this assignment did not apply any data about the industry of commerce. Since the reported estimated damage includes a lot of facets that are not taken into account in this assignment and vice versa, the comparison is not fully accurate. However, it does give a good indication of the significance of the damage in this assignment.

3.2. Mortality

3.2.1. Mortality map

Using the mortality curves of Jonkman & Asselman (s.a.) for both rapid water rising and slow water rising, the results are extremely high (see table 3.3). Figure 3.3 shows the mortality map of the slow water rising curve with HEC-RAS inundation depths. In this map the amount of fatalities per grid cell (8100 m²) is shown, with a maximum of 715 casualties. The map exposes that almost every surface that is inundated will cause deaths to the population. The biggest losses are at the banks of the Huong River itself, in Hué City.

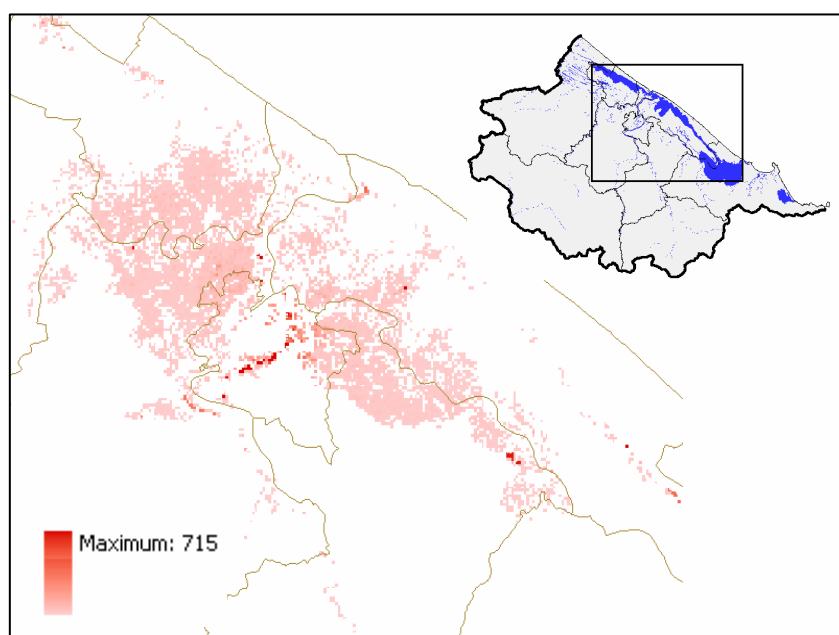


Figure 3.3: Mortality map with slow water rising curve and HEC-RAS inundation depths

	HEC-RAS inundation depths	Observed inundation depths
Rapid water rising curve	20.431 fatalities	48.983 fatalities
Slow water rising curve	2.319 fatalities	2.821 fatalities

Table 3.3: Total calculated fatalities due to a flood with discharges of the November 1999 flood

In table 3.3 it is not necessary to involve both the HEC-RAS inundation depths and the observed inundation depths to expel the HEC-RAS model accuracy, since they are alike in proportion to the results of the mortality model, see the validation of the mortality map.

3.2.2. Validation mortality map

According to the reports of international organisations (Reliefweb – USAID, 1999) and the local newspapers, the number of fatalities due to the November 1999 flood is 622 (see table 3.4). This number is much smaller than the smallest calculated amount with the curves of Jonkman & Asselman, so the implementation of these curves is not valid at all. The mortality map is now only to use for an indication of the locations of the areas where a high inundation is predicted together with a high population density.

Casualties reported by international organisations	
People killed	622
People missing	70
People injured	412

Table 3.4: Reported casualties

3.3. Validation inundation map

3.3.1. Spatial comparison

When the HEC-RAS inundation map is compared with the observed inundation map (see figure 3.4), it becomes clear that according to the HEC-RAS model a smaller surface is inundated than in reality happens. 72 Percent of the HEC-RAS inundated area is similar to the location of the observed inundated surface, 28 percent of this area is in reality not inundated.

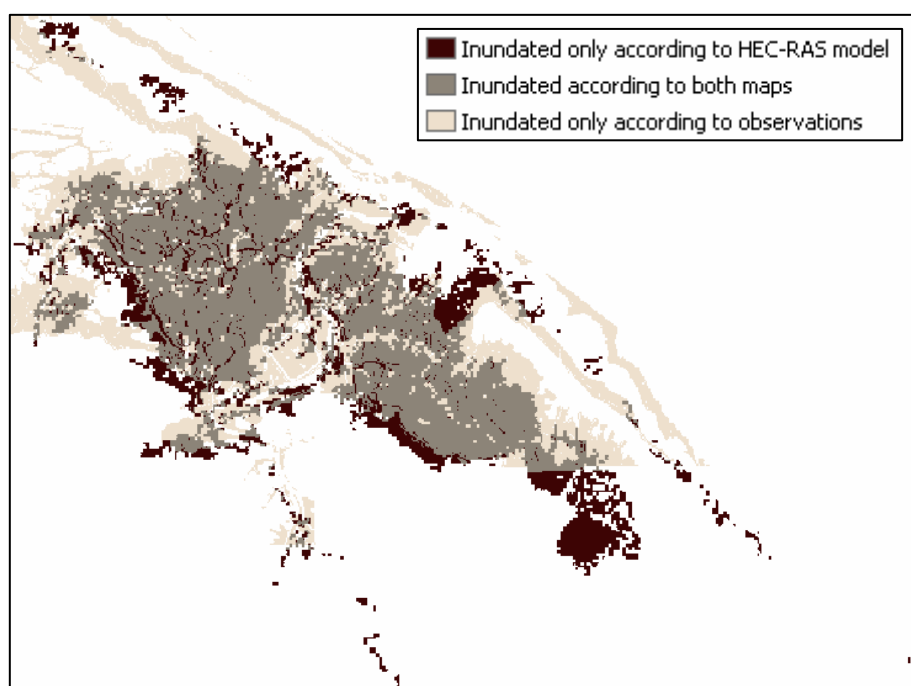


Figure 3.4: Spatial comparison

It has to be noted that the data of the observed inundation map does not stretch as far as the data of the HEC-RAS inundation map. As one can see in figure 2.16, this data has a boundary in the South East of the map. This explains the area in the South East that is

inundated only according to the HEC-RAS model. Taking this into account, the numbers and percentages stated in table 3.5 would be much more positive concerning the accuracy of the HEC-RAS model.

3.3.2. Qualitative comparison

Dividing the HEC-RAS inundation data to the categories of the observed map, 26 percent of the similar surface is predicted correctly by the HEC-RAS model. The correct data is spread over the whole map, except for the area where the Huong River floods into the lagoons. This can be concluded since no black spots at that location in figure 3.5 can be seen. This assumes that the prediction of the HEC-RAS model in general is of moderate quality, except for the estuary of the Huong River.

		Km ²	%
Spatial comparison	Surface inundation of the observed inundation map	370	100
	Surface inundation of the HEC-RAS inundation map	276	75
	HEC-RAS inundation surface within the observed data	201	54
	HEC-RAS inundation surface outside observed data	75	20
Qualitative comparison	HEC-RAS inundation surface within the observed data	201	100
	Similar spatial data	52	26

Table 3.5: Spatial and qualitative comparison

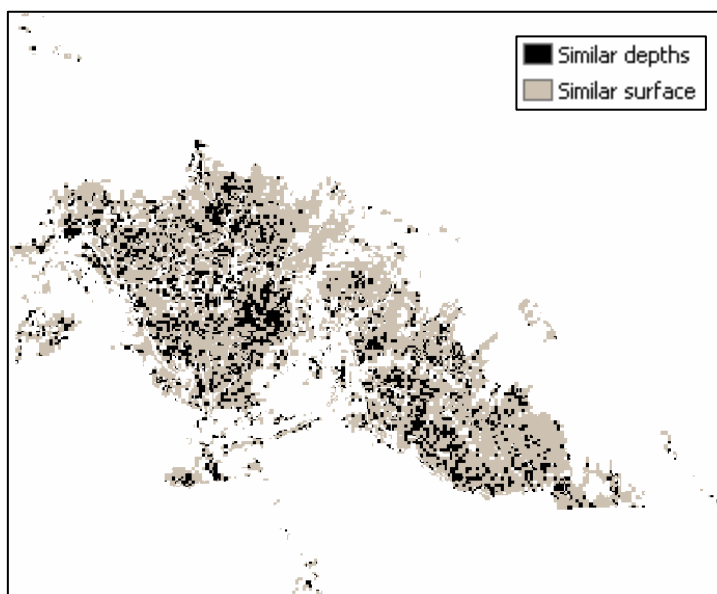


Figure 3.5: Spatial comparison

3.3.3. Depth line comparison

The depth lines from West to East and from North to South are drawn in figures 3.6 and 3.7. As one can see, the HEC-RAS data is more accurate since these are not divided into categories like the observed data are. The observed depths should be considered indications for their categories, since each category has gained its own value (see part 2.3.2. *Validation HEC-RAS inundation map*). On the x-axes, the grid cells of Matlab are stated, each cell is 90 meter width and 90 meter long. For the North-South line the data left and right is cut off, since this part of the map contains no data.

Some peaks are missing in the HEC-RAS data while they do exist in the observed data. But in general, when the HEC-RAS data does predict inundation, it often has a valid depth. Over the West-East line a large peak between cell 0 and 80 is drawn very small and two small

peaks in the East are missing. This means that the HEC-RAS model takes only a little notice of the inundated area upstream of the Bo River and no notice of the inundated area at the banks around the lagoon in the East. Alongside the North-South line, the HEC-RAS model does not predict the small peak in the North and it practically takes no notice of the many small peaks in the South. The inundated area in the North-West of Hué is predicted pretty accurately.

Over all, it seems that the HEC-RAS model predicts accurate inundation depths, but the accuracy is lacking for the surface that inundates.

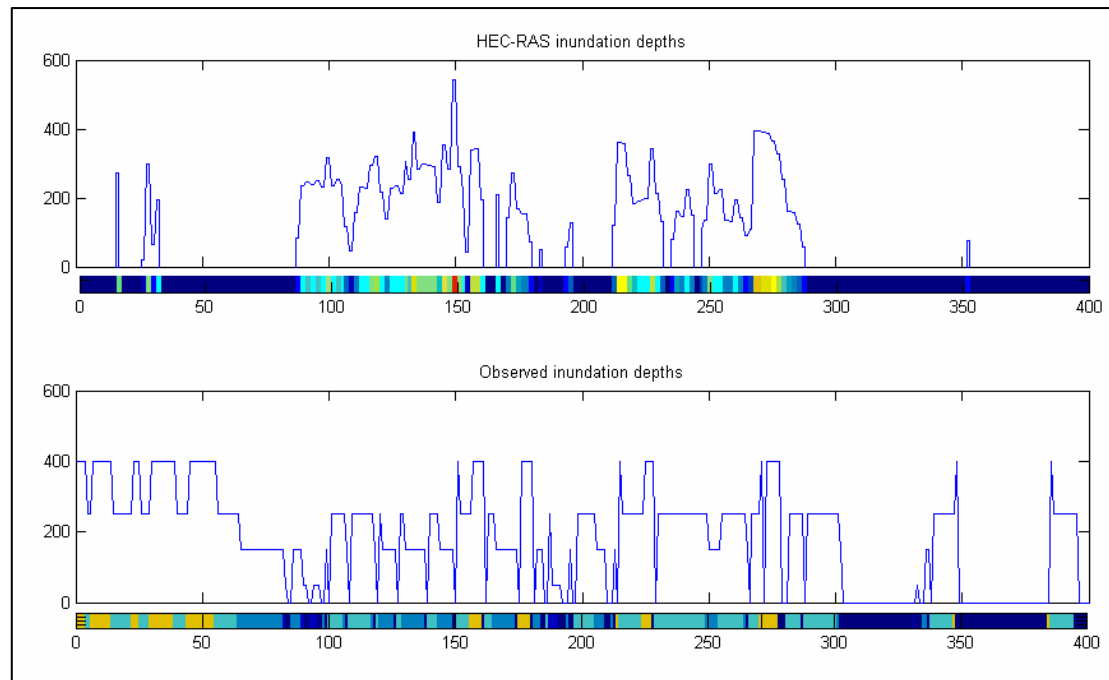


Figure 3.6: Water depth line (in cm) from West to East (per Matlab cell of 90 meter)

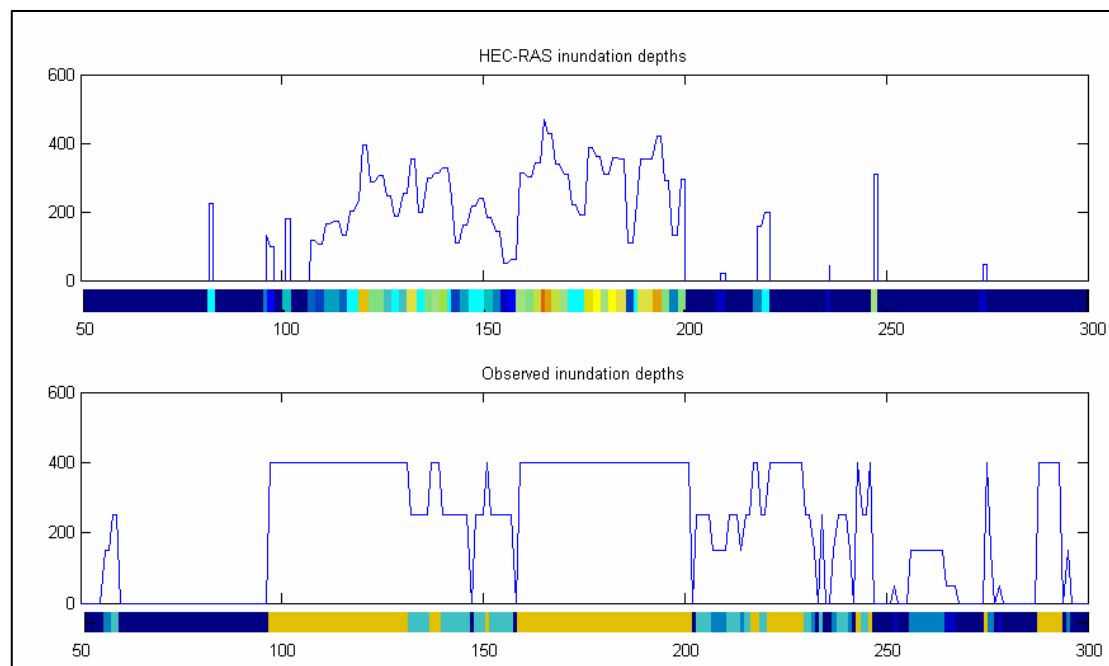


Figure 3.7: Water depth line (in cm) from North to South (per Matlab cell of 90 meter)

Chapter 4. Conclusions

4.1. Conclusion

Local applicability depth-damage function

The used depth-damage curves seem to be capable of prediction of the amount of damage, since the accumulation of the damage of several land use types for inundation depths of the November 1999 flood appears to be in the same order as the reported damage for that particular flood. This means that the consequences of flooding of the Huong River can be predicted, as long as the prediction is limited to the economic damage.

The mortality is not to be predicted with the depth-mortality curve of Jonkman & Asselman (s.a.). Applying this curve with the inundation depth and the population density of the Thua Thien Hué Province, results in an extremely high number of fatalities, until two orders of magnitude above the reported amount of fatalities due to the November 1999 flood. Only the spatial data of the mortality map can be used as a lead to the risks that the population is subject to, but for this only a simple comparison with an inundation map and the density map is already sufficient. When comparing these, the South bank of the Huong River in Hué City would be the location of the most fatalities during a flood.

Economic consequences

For the economic damage in case of a flood like the November 1999 flood, the area around rivers in the Huong River Basin is also subject to the largest consequences. This is mostly caused by the rural settlement near the rivers and its large vulnerability for flooding. The rural area has the largest share in the total damage and suffers the second largest surface of inundation, after the rice fields. Determining the damage per square meter, it appears that the railroad and the highways suffer the most extreme damage, followed by the urban settlement. When forest area or rice fields are struck by inundation, its maximum damage is reached with only a small water depth, since the average damage of both land use types is nearly the same as their maximum damage values.

Sufficiency HEC-RAS model

The developed HEC-RAS model of the Huong River Basin is sufficient in predicting reasonable inundation depths, but these predictions are only valid in the centre of the inundated area. In the boundary areas such as upstream the Bo River, near the estuary of the Huong River and around the lagoons the HEC-RAS model does not predict any inundation, possibly due to lack of detail in the used digital elevation map. This means that the model is insufficient about the inundated surface, but the data within its prediction of the inundated areas is useful for a damage model like this assignment.

4.2. Discussion

Accuracy observed inundation map is lacking

This assignment assumes that the observed inundation model contains the valid and accurate data of the November 1999 flood. Since it is not known how this map is obtained and what assumptions have been made creating this map, the accuracy of the observed inundation map is doubtful. This influences the accuracy of the validation. Moreover, it seems that the observed inundation map did not take into account details that can influence the validation. For instance, the highways and railroads in reality sometimes are built on small dikes, while the observed inundation map does not register these small depth differences.

Since these small differences are also not traceable in the HEC-RAS model, the accuracy of the HEC-RAS model can appear good by a validation with the observed data, while the accuracy of the observed data invalidates this conclusion.

Data of land use types is incomplete

Only a small amount of land use types is processed by this assessment. These types do not represent all the existing land use types in the Huong River Basin. This means that not all the possible economic damage that the Huong River Basin suffers, is taken into account. For example the industry, the commerce, tourism, fishery, recreational areas and temples would be subject to damage. These land use types as well, will suffer economic losses due to flooding. Since these types are not taken into account in this assignment, this damage map can create a limited image of the reality.

Furthermore, the accuracy of the validation is affected by the age of the data of the processed land use types. This assignment used the most recent spatial data of land use types, while the data for the validation dates back to 1999. The discharges of the November 1999 flood are used to simulate this flood, while the spatial data of the land use types is dated from 2007. Since 1999, the industry and tourism have grown and the house value increased, so the vulnerability for flooding must be higher too and the damages should be estimated higher. However, while this recent data implies that the validation is less accurate, the data is still useful for the prediction of economic consequences of future floods.

Detailed data of the damage map is not validated

Although the total damage of the damage map is validated, the amounts of damage per land use type are not validated. Now it can be a coincidence that the total amount of damage seems to be right, since it is possible that corrupt data of one land use type can be corrected by the corrupt data of an other land use type. Validating the several land use types is only possible when data of the damages per land use type is available. Now the conclusions concerning the proportions of the damages or the spatial data per land use type can be considered guidelines and should not be considered validated.

Lots of variables are not taken into account

The HEC-RAS model only provides water depths, whereby the characteristics of the flooding that are used in the damage map, are limited. If data such as water velocity, rising speed, duration of the flood, wind speeds, and possible preparation for flooding would be available, the damage map could be modelled with more accuracy. These variables can influence the damage map by more detailed information about the damage that buildings and assets suffer, by which the damage can be defined more accurately.

For the mortality map the lack of data is larger and even more important. Mortality is dependent of many variables like warning systems, evacuation time, evacuation possibilities, water rising speed, water depth, people's behaviour during a flood, the velocity of the water and the average repetition time of the flood. These variables all exert a great influence to the number of people that drown in case of a flooding. When these variables would available, more accurate information could be acquired about the mortality and therefore about a mortality map.

Mortality function

The applied mortality function has proven no use for the Huong River Basin. However, when applied in other cases, it should be considered that the function was derived for a situation in which the people were surprised and there was no time for evacuation was possible. In case

of a flood of the Huong River, the residents are often warned by the prediction of a typhoon. These people should be able to prepare and to flee. In other assignments, first the number of people present should be estimated considering the possibilities of an evacuation.

Different resource data sets

This assignment was dependent of the available data concerning the inundation depths, the population density and the land use types. Some of these data files had wrong or no spatial location attached, therefore some data files have been given spatial data manually. This is done by comparing reference points within the maps such as the recognisable shape of the Hué citadel. Although, still one can not be sure that all the spatial data of the maps now is correct. A tiny difference between the inundation map and the land use map can have a significant influence to the details of the damage map. Considering this, the damage map should be used as a guideline for general damages at a larger scale than the presented grid of 90 x 90 meters.

4.3. Recommendations

The final goal of this assignment and all the work that has been done in preparation to this assignment, is to develop a tool to describe the vulnerability of the Thua Thien Hué Province concerning a flood of the Huong River. This description can be useful to reduce economic and social consequences.

This assignment created the insight that the developed HEC-RAS model of the Huong River Basin is sufficient to predict reasonable inundation depths, but it does these predictions only in the centre of the inundated area. This model should be developed further to obtain more significant data in the boundary areas, such as upstream the Bo River, near the estuary of the Huong River and around the lagoons.

Implementing the depth damage curve seems to be a good method creating the damage map with the little information available. The result is reasonable but the quality of the resulting spatial data is not validated at all. As long as no extra data is present besides the inundation depth and the land use available, the used damage curves should be used. However, it is recommended to validate them.

Of course it is recommended to expand the significance of the damage map by updating and adding data. The inundation data should be more significant and the land use data can be expanded with data about the industry, commerce, tourism and fishery. However, not only this data should be collected, also compatible depth-damage curves are necessary for these new datasets.

It is recommended not to use the depth-mortality curve of Jonkman & Asselman (s.a.) for the estimation of fatalities in the Huong River Basin. To make such an estimation a curve should be obtained that is developed for a similar area as the Thua Thien Hué Province, that is often struck by floods and a where the population is better informed of the flooding risks.

Assuming the data of the economic damage map is correct, much attention about consequence decreasing should go to the rural settlements. The rural settlements suffer effectively the most damage during a flood in the Huong River basin. Reason is its great vulnerability for flooding and these settlements are often located in heavily inundated areas.

References

- Tran P., Shaw R., Chantry G., Norton J. (2007) *"GIS and local knowledge in disaster management: a case study of flood risk mapping in Vietnam"*. Graduate School of Global Environmental Studies, Kyoto University, Japan and Development Workshop, France.
- Vermue H. (2006). *"Flood modeling and measure assessment for Huong River Basin"*, Bachelor thesis, University of Twente.
- Reliefweb – Red Cross (1999). *"Vietnam: Floods Situation Report No. 1"*. Source: International Federation of Red Cross And Red Crescent Societies, 25 November 1999. <http://www.reliefweb.int/rw/rwb.nsf/db900SID/OCHA-64BKUY?OpenDocument> [Downloaded on 25 September 2007].
- De Oude R. (2006). *"Flood modeling of the Huong River System in Thua Thien Hué, Vietnam"*, Bachelor thesis, University of Twente.
- De Bruijn K.M. (2005). *"Resilience and flood risk management"*, DUP Science, Delft University Press.
- Huang Y. (2005) *"Appropriate modelling for integrated flood risk assessment"*. University of Twente. (ISBN 90-365-2251-x).
- Kok M., Huizinga H.J., Vrouwenvelder A.C.W.M. & van den Braak. W.E.W. (2005). *"Standaardmethode 2005 Schade en Slachtoffers als gevolg van overstromingen"* (Standard Method), Rijkswaterstaat DWW.
- CRUEIP (2003). Central Region Urban Environmental Improvement Project, *"Supplementary Appendix to the Report and Recommendation of the President to the Board of Directors"* [Resettlement plan], Provincial People's Committee of Thua Thien Hué.
- Gupta A.D., Babel M.S. & Ngoc P. (2004). *"Flood damage assessment in the Mekong Delta, Vietnam"*, Water Engineering and Management, School of Civil Engineering Asian Institute of Technology. [Downloaded August 14, 2007] <http://www.wrrc.dpri.kyoto-u.ac.jp/~aphw/APHW2004/proceedings/FWR/56-FWR-M167/56-FWR-M167.pdf>
- VDP (2004). Vietnam Disaster Prevention, *"Renewal of housing stock has increased vulnerability to loss"*, *"Building types"* & *"What is involved in house reinforcement?"* <http://www.vietnamdisasterprevention.org> [Downloaded on September 19, 2007].
- AUDMP (2001). Asian Urban Disaster Mitigation Program, *"Workshop on Safer Shelter in Vietnam 4-5 September 2002"*, [Downloaded on September 10, 2007] <http://www.adpc.net/AUDMP/library/proceedings/vn1.pdf>, ADPC.
- Jonkman S.N. & Asselman N. (s.a.). *"Method for the Estimation of Loss of Life Caused by Floods in the Netherlands"*. GIS & RS in Hydrology, Water Resources and Environment, Volume 1. WL | Delft Hydraulics, The Netherlands.
- Reliefweb – USAID (1999). *"Vietnam Floods Factsheet #1, FY 2000"*. Source: United States Agency for International Development, 18 November 1999. <http://www.reliefweb.int/rw/rwb.nsf/db900SID/OCHA-64CT54?OpenDocument> [Downloaded on 25 September 2007]
- Messner F., Penning-Rowsell E., Green C., Meyer V., Tunstall S. & van der Veen A. (2006). FLOODsite report : *"Guidelines for Socio-economic Flood Damage Evaluation"*. <http://www.city.tudelft.nl/live/binaries/a4751543-3c3e-4787-b3c2-ae34f717f351/doc/citatie242.pdf> [Downloaded on August 4, 2007].

- van der Veen A. & Logtmeijer C. (2004). "*Economic Hotspots: Visualizing Vulnerability to Flooding*", Department of Business, Technology and Public Policy, University of Twente, Springer 2005.
- Genovese E. (2006). "*A methodological approach to land use-based flood damage assessment in urban areas: Prague case study*", European Commission Directorate-General Joint Research Centre. [Downloaded on Oktober 15, 2007]
http://ies.jrc.cec.eu.int/fileadmin/Documentation/Reports/Land_Management/EUR_2006-2007/EUR_22497_EN.pdf
- van der Sande C.J., de Jong S.M. & de Roo A.P.J. (2003). "*A segmentation and classification approach of IKONOS-2 imagery for land cover mapping to assist flood risk and flood damage assessment*", International Journal of Applied Earth Observation and Geoinformation, pp. 217–229.
- van der Sande C.J. (2001) "*River flood damage assessment using Ikonos imagery*", Natural Hazards Project-Floods, Joint Research Centre of the European Commission, S.P.I. 01.147, Ispra, August 2001.http://natural-hazards.jrc.it/documents/floods/2001-docs/2001-reports/flooddamage_report.pdf [not available]
- Briene M., Koppert S., Koopman A. & Verkennis A. (2002). "*Financiële onderbouwing kengetallen hoogwaterschade*". NEI, Rotterdam, The Netherlands.
- Kok M (2001). "*Damage functions for the Meuse River floodplain*", Communication paper to the Joint Research Centre, Ispra, Italy, 10 pp. [not available]
- Penning-Rowsell E (2001). "*Stage-Damage Functions for Natural Hazards Unit*". Flood Hazard Research Centre, Middlesex University, England. Communication Paper to the Joint Research Centre, Ispra, Italy, 3 pp. [not available]
- IKSR (2001). "*Rhine Atlas 2001, Damage*". Internationale Kommission zum Schutz des Rheins, Druckbetriebe Lettner KG. <http://www.iksr.org/index.php?id=29> [Downloaded on August 4, 2007].
- Dutta D., Khatun F. & Herath S., (2005). "*Analysis of Flood Vulnerability of Urban Buildings and Population in Hanoi, Vietnam*" Seisan Kenkyu 57, 338.
- Nghiem Tien Lam (2002). "*A Preliminary Study on Hydrodynamics of the Tam Giang – Cau Hai Lagoon and Tidal Inlet System in Thua Thien-Huế Province, Vietnam.*" International Institute for Infrastructural, Hydraulic and Environmental Engineering, Delft, The Netherlands.
- Villegas P. (2004). "*Flood modelling in Perfume River Basin, Huế Province, Vietnam*", ITC, International Institute for Geo-Information Science and Earth Observation. Enschede, The Netherlands.
- H2iD (2005). Hulsbergen Hydraulic Innovation and Design. "*Flood Vulnerability Analysis and Mapping in Viet Nam*" NIVR project number 53407PAN. The Netherlands Agency for Aerospace Programmes and the SRON Netherlands Institute for Space Research.
- Bouwer L.M. & Aerts J.C.J.H. (2005). "*The impact of land-cover change and climate variability on river runoff*". NIVR project number 52308IVM, Institute for Environmental Studies, VU University Amsterdam, The Netherlands.
- Bouwer L.M. & Aerts J.C.J.H. (2005). "*Calibration and validation for the wider Perfume River Basin in Vietnam*". Part of NIVR project number 52308IVM, Institute for Environmental Studies, VU University Amsterdam, The Netherlands.
- Nguyen Khac Tien Phuoc, (s.a.). "*Flood Hazard Modeling in Thua Thien Hué Province,*

Vietnam", Unesco-IHE Institute for Water Education, MSc researches.
http://www.unesco-ihe.org/about/academic_departments/hydroinformatics_and_knowledge_management/msc_research_topics/flood_hazard_modeling_in_thua_thien_hue_province_vietnam [Abstract downloaded on November 10, 2007].

DEFRA (2004). Department For Environment, Food and Rural Affairs, "*Making space for water: Developing a new government strategy for flood and coastal erosion risk management in England: A consultation exercise.*" London: Defra.

Attachments

Attachment A: Literature Review

This assignment is founded on literature about damage functions and mortality concepts. The information of the considering literature that is significant for this assignment is summarised and presented in this literature review. Finally, all the known researches in the same area are summarized.

Damage functions

Damage functions exist in many types and are used in many different approaches. First, the literature about the possible damage functions is obtained. Then the damage function is unravelled in damage curve and the associated maximum damage value. Finally the known damage assignments that have been carried out in Vietnam are presented.

Flood damage functions

Messner et al (2006) provide a guideline for socio-economic flood damage evaluation. Their FLOODsite report bundles different approaches of flood damage. A difference is made between damage functions on the levels macro, meso and micro. Micro uses the most precise data and costs the most effort per unit of area, it is for implementation on local scale. Macro has the least precise data output, but can cover more area with the same efforts and is best used for large (international) areas. Meso is in between these levels, and therefore it is best to implement a meso approach on regional scale. Furthermore, the FLOODsite report provides a couple of questions that can give insight considering the best approach per damage assignment.

Van der Veen & Logtmeijer (2004) extend the known concept about damage functions with the indirect economic effects on the rest of the regional and national economy. He introduces the definition 'vulnerability', a function of dependence, redundancy and susceptibility. When an area with high vulnerability (an economic hotspot) is flooded, the significant indirect consequences must be taken into account.

Genovese (2006) carried out a damage assignment for the 2002 flood in Prague, Czech Republic. She used damage curves and maximum damage values of Kok (2001), Van der Sande et al (2003) and Van der Sande (2001) to determine the damage per square meter. These resources are of use to understand the foundations of the damage curve and the associated maximum damage value.

Briene et al. (2002) studied the financial foundations of the prefixes concerning damage due to flooding. The article is not available.

Van der Sande et al (2003) create detailed land cover maps using satellite images, to implement these in a damage function collected from the articles of Kok (2001) and Penning-Rowell (2001) and an old version of the Standard Method of Kok et al. (2005). The damage curves of this function are presented but the foundations for these curves to recreate maximum damage values for the Vietnam area should be obtained from the resources.

Huang her thesis (2005) goes into the gap between scientific knowledge available and its implementation of decision support system, when river basin management applications are used. The thesis deals with the difficulties related to the selection and performance evaluation of hydraulic models for Flood Risk Assessment (FRA). Also the improvement of the current FRA approaches is subject. Among other FRA's, the FRA using depth-damage curves of Kok (2001), IKSIR (2001) and Van der Sande (2001) is listed.

However, the articles of Kok (2001), Penning-Rowsell (2001) and Van der Sande (2001) are not available. Their functions can be taken from the thesis of Huang (2005), but the only resource for the foundations of these damage functions is the Standard Method of Kok et al. (2005).

Damage curves

The Rhine-Atlas of the IKS (2001) creates a damage map for the Rhine, using self developed damage curves. These curves use the inundation depth determine the damage factor. With the maximum damage values per land use the damage map is created. For the estimated value and the vulnerability per land use, IKS first calculates the value of the affected assets and then defines the material damage. The affected assets are determined by their mean values. Local data is obtained by German statistics, which is extrapolated for other areas. The used functions are dependent on the available data for land use, in this case of the CORINE database. Considering this, the damage functions are separated into mobile and immobile assets.

In The Netherlands, the government has developed the Standard Method (Kok et al, 2005) to calculate the amount of expected damage and victims due to a flooding. With these calculations, risk analyses can be done in vulnerable areas. The Standard Method is the result of the adjustments from several studies concerning the same subject to the Standard Method of 2000. The Standard Method provides damage curves that use damage factors per land use, dependent of the inundation depth. This damage factor comes with maximum values per land use, that here is specified for the Dutch environment.

Maximum damage values

The supplementary appendix of the Central Region Urban Environmental Improvement Project (CRUEIP, 2005), provides the values for land acquisition and resettlement requirements concerning this project. This resettlement plan aims to improve the conditions in five poor towns in the Thua Thien Hué Province, constructing infrastructure and facilities. The replacement values are estimated on land use data in each project area and on technical designs. The provided replacement values are not yet fully adapted to the actual households affected by the project and the actual market value, but it provides an indication of the replacement costs of some assets.

Damage assignments in Vietnam

Development Workshop carried out a participatory Geographic Information System hazard-mapping project in Vietnam (Tran et al, 2007). Linking community knowledge of local flooding risks with modern techniques, Tran et al were capable to give the local communities the possibility to participate in decisions concerning disaster management. The implemented damage function uses data acquired from households in a village in the Thua Thien Hué Province, and separates the households in risk categories using the weights 'intensity of natural events', 'exposure to the hazard' and the 'vulnerability for harm due to a hazard'. The methodology of this research is of value for a local assignment.

Dutta et al (2005) have analysed the vulnerability of the buildings in Hanoi for urban flood disaster management. Using the characteristics of households for variables, multiple regression analyses were carried out to develop relationships between flood damage and carefully selected variables. Dutta et al calculate the total property damage for a building as the sum of 'structural damage', 'content damage', 'outside property damage', 'cost for flood prevention measures' and 'cleanup costs'. Many variables are needed for these calculations, but are not available for the assignment in the Huong River Basin.

Vietnam Disaster Prevention (VDP, 2007) is a project of the Development Workshop in France, that has the goal to improve the precautions for hazards in local communities. Therefore, field studies are done to collect information about the households and circumstances. This information can be helpful for this assignment to develop maximum damage values for damage functions.

Gupta et al (2004) based their flood damage assignment on the actual flood damage information available for the year 2000 flood and the potential flood damages to different categories of land use activities in the delta obtained through questionnaire survey. However Gupta et al mainly collected average damage due to this flooding, some data can be used in order to create maximum damage values in this assignment.

De Bruijn (2005) attends to the matter of resilience and researches how the resilience of a flooding risk area should have impact to the precautions for flooding. The research proved that resilience and resistance are both system characteristics that express the ability of an area to cope with flooding. One of the case studies is done in the Mekong Delta, Vietnam, and uses a depth-damage function to calculate the damage due to flooding. This function can be used in this assignment.

Research in the Huong River Basin

Nghiem Tien Lam (2002) studied the hydraulic characteristics of the Tam Giang-Cau Hai lagoon system. The main objectives were to set-up a numerical model to simulate and investigate the hydraulic behaviour of the system to evaluate the stability situations of the inlets. A 1D numeric model is used to simulate the hydraulic behaviour of the system. The model results indicate that river flows are the most important acting force of the system during floods. In the dry season, the most important factors influencing the hydrodynamic characteristics of the system are tides, sea level rise and inlet openings. The stability situation of the Thuan An inlet is in a "fair to poor" situation, the Tu Hien inlet, is always in a "poor" stability condition.

In the study of Villegas (2004), data of the Tropical Rainfall Measuring Mission (TRMM) is compared with ground rain gauge records through the discharges obtained by GIS modelling. The comparison shows that the most reliable estimation during the flooding period so far is the TRMM data. The rain gauge collected data is more efficient during the normal conditions. A reservoir model was developed to estimate the volume of water stored in the flood plain and the temporal variation of the flood was estimated using a digital elevation map inundation technique.

H2iD (2005) uses the topographic height and its aspects, land use and the land use changes as input for simple, easy-to-understand vulnerability maps for the wider Huong river basin, the Mekong river basin and the Red river basin. H2iD gave a series of workshops for Vietnamese that indicated an interest in applying the flood vulnerability methodology in practice. This has led to a global flood vulnerability service via the Internet to publish this kind of information to interested citizens and professionals.

The project of Bouwer & Aerts (2005) "*The impact of land-cover change and climate variability on river runoff*" aims at comparing the Huong River in Vietnam and the Krishna River in India in terms of land use changes and climate change impacts, to improve the quantification of these terms. Bouwer & Aerts use the STREAM¹ model to visualise the spatial patterns of land

¹ STREAM is a GIS raster model that simulates discharges in a river basin using a spatial water balance model

cover change and evaporation and for an assignment of potential hydrological impacts due to climate change. The project shows the usefulness of remote sensing data to calculate the water balance in the STREAM model. Additionally, it demonstrates what possible future changes can be potentially expected in the river basins and low-lying coastal areas, using estimations concerning the impact of land-cover change and the potential impacts of climate change on river hydrology.

The Huong River case in the project of Bouwer & Aerts (2005) is described in detail in the sub article "*Calibration and validation for the wider Perfume River Basin in Vietnam*". The results show that the model very well predicts discharges in the upper reaches of the river basin, but discharges closer to the coastline are not very well represented. The annual discharges simulated by STREAM are matching both calibration and validation numbers, but the base flow of the peaks and base flow of the simulations is underestimated in summer. The article concludes that there is a need for better understanding of the downstream discharges.

The research of Nguyen Khac Tien Phuoc (s.a.) aims to undertake a flood hazard study in the Thua Thien Hué Province by applying ArcGIS 9 for terrain analysis, MIKE11 to replicate hydrodynamic processes and waterRIDE to produce the inundation and flood hazard maps. The rainfall-runoff results of the November 1999 flood, obtained by NAM model, were used as upstream boundaries for the hydrodynamic model. The water depth and velocity values were used in calculation of flood hazards and such information was presented in a GIS-map. The maps produced show useful information about flood hazards in this region which after some adjustment of parameters correspond to the November 1999 flood.

Vermue (2006) and De Oude (2006) created the foundation of the Huong River Basin system in HEC-RAS software. Their researches focus on increasing insight in the hydrodynamic processes and testing measures to improve the flood drainage capacity of the system. Validation results were not satisfying, since the input data was not yet sufficient and problems within the model occur due to lack of data. Tran Anh Phuong of the Hanoi University of Science has carried on their research in 2007 and simulated the November 1999 flood. Although this is still not a accurate simulation, this model can be used to predict the inundation depth for certain amounts of rainfall.

Attachment B: Approach for economic damage mapping

The FLOODsite report of Messner et al (2006) separates the available damage functions into the scales macro, meso and micro. Within each scale some differences are made considering the necessary precision, the resource data available and the pre-existing data. These characteristics are here taken into account to come to a recommended approach.

Overall, a meso scale approach is desirable since this assignment covers a regional area. The Huong River Basin covers an area of 3760 square meter, more than half the size of the Thua Thien Hué Province. For this scale, medium demands on precision are necessary and that corresponds to this assignment. More precision would be suitable for an assignment in a local village, less precision is suitable when a whole country is involved. The approach within the meso scale approaches to be used, depends on the amount available resource information. The more time and money is at hand, the more a precise and accurate the resource data can be acquired and the better the result of the assignment will be.

	Approach	Approach of Kok et al. (2005)	Approach for this assignment
Step 1	Data requirements	Among others: - Aggregated land use data	Available: - Aggregated land use data
Step 2	Damage categories considered	Among others: - Buildings - Infrastructure	- Residential area (urban and rural) - Infrastructure (roads and railways) - Agriculture (rice and other crops) - Forest area
Step 3	Inundation characteristics needed	- Area - Depth - velocity, waves	Inundation depth (observed and predicted)
	Land use data	Mixture of different data sources, merged to one file with 100 meter grid.	Mixture of data of Thua Thien Hué Province and National University of Science, Hanoi. Merged to Matlab matrices with 90 meter grid.
	Determination of values of assets	- Maximum damage per unit - Official statistics and insurance values	- Maximum damage values per square meter, per land use type - Preliminary research in published articles
	Damage functions	11 relative depth-damage functions, assigned to asset categories.	Different depth-damage functions, each adapted to one land use type.
Step 4	Damage calculation and presentation	Damage is calculated for each grid cell. A GIS-based software tool is developed to facilitate damage calculating and mapping.	Damage is calculated for each grid cell. Available data will be converted into Matlab matrices, to calculate the damage and map it in ArcView with the spatial data of the resource data.

Table A-1: Damage assignment approach at meso scale

For this assignment, only one person is available during three months, so mainly the pre-existing resource data that is collected before this period, is available. The data presented in part 2.1.2. *Input* and part 2.2.1. *Input* is the resource data. It is a combination of aggregated data and object-oriented data. For example, the urban area is aggregated data because more than only houses are located in the particular area. The projected infrastructure is object-oriented data. The FLOODsite report recommends the approach of Kok et al (2005) for the aggregated data. For the object-oriented data only the approach of DEFRA (2004) is recommended. The steps that Kok et al use, are introduced in table A-1. The steps of DEFRA are neglected, because this report uses object-oriented data that has the asset value available. This assignment is not in possession of this kind of data and therefore it is dependent on the approach of Kok et al.

The steps of the approach of Kok et al are processed in this assignment using part 2.1. *Damage mapping* and part 3.1. *Economic damage*. The strings that are used to implement the damage functions are documented in Attachment C *Matlab strings*.

Attachment C: Matlab strings

In Matlab, several steps have been taken to create the damage map and the mortality map, and finally to validate them. In this attachment the methodology and the Matlab strings themselves are documented.

Methodology

Matlab software (version 7.0.0.19920, R14) is used to collect the necessary data and to manage this data. The data of the land use types and of the inundation depths was available in shape files (.shp) with polygons and some data was available in TAB files. The TAB files can be converted in MapInfo Professional (version 8.0) to shape files and in ArcMap software (version 9.2) these files can be converted to a raster file. From a raster file (.img) it is possible to make a ASCII file and this can finally be read and be managed by Matlab. The resulting maps from Matlab are converted to shape files again to view the maps in their spatial location. Reading and writing the ASCII files without losing the spatial data can be done with the scripts 'readARCAscii' and 'writeARCAscii', see Matlab script 2.

Since the input data for the damage function is collected from several resources with not all the same spatial data, the maps had to be relocated and to be resized to one and the same map size. The relocation of the maps has been done manually (see Matlab script 2), using reference points in the data itself to control the location. The maps have been resized to the size of the HEC-RAS inundation map, since the data outside this map is of no use for the damage map. To resize the land use maps, per land use type a new map is created, with the length and width of the HEC-RAS inundation map (in the Matlab strings referred as map1). Before adding the land use data, it is determined what the differences between the sizes of the land use map and the inundation map are (see Matlab string 4, figure A-1 and table A-2).

Applying the determinations of the differences between the map sizes, the land use data is added to the new land use maps. (see Matlab string 7). At last, it should be assured that the sizes of the new maps are similar, since it is not possible to apply functions to maps of different sizes (see Matlab string 8).

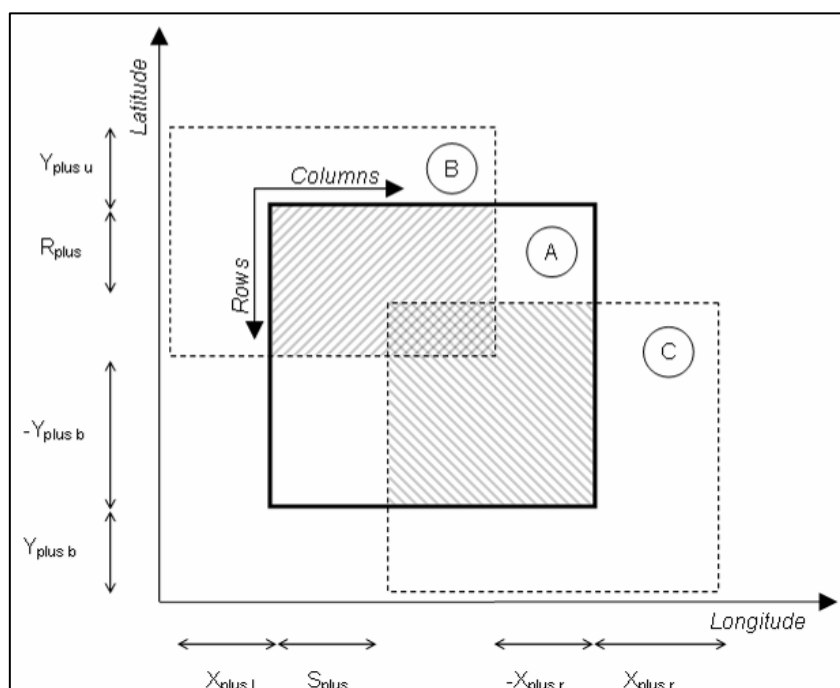


Figure A-1: Units used for adjusting spatial data land use maps

To implement the damage function and the mortality function, first the depth-damage/mortality curves are defined with Matlab string 9. These are applied with Matlab strings 10 and 11.

The validation of the inundation map is done with several methods, for each method a Matlab string is created. The spatial comparison has been done using Matlab string 12. For the qualitative comparison Matlab string 13 is used and for the Depth line comparison Matlab string 14 is applied.

To validate the damage map itself by a qualitative comparison a Matlab string has been developed by this assignment (Matlab string 15). It has not been used since no data was available concerning the real damages due to the November 1999 flood, but it may be possible in the future.

Legend figure A-1	
	Map with goal dimensions (inundation map)
	Map with different dimensions (land use maps)
	Part of land use map that is taken into the goal map
	Part of land use map that is taken into the goal map
Yplus u	Cut from above
Yplus b	Cut from below
Xplus r	Cut from right
Xplus l	Cut from left
-Yplus b	Fill up from below
-Xplus r	Fill up from right
Splus	Fill up from left
Rplus	Fill up from above

Table A-2: Legend for figure A-1

General strings

```
clear all
addpath C:\Matlab
addpath C:\Matlab\Resources
```

Matlab script 1: Start with new entries and add directories

```
[map1,ncols(1), nrows(1), x11(1),y11(1),cellsize(1), nodatavalue1 ] = readARCAscii('tinhtoan-90.txt',0);
(...)
writeARCAscii(map1,'HEC-RAS_inundation.txt',0,ncols(1), nrows(1), x11(1),y11(1),cellsize(1),
nodatavalue1);
```

Matlab script 2: Load ASCII file with tool 'readARCAscii' and write Matlab map into ASCII file with tool 'writeARCAscii'. Spatial location of the map can be changed manually by adjusting x11(1) and y11(1) (left lower corner)

```
cellArea = cellsize(1)^2;
X1 = [0:cellsize(1):cellsize(1)*ncols(1)];
Y1 = [0:cellsize(1):cellsize(1)*nrows(1)];
figure(1)
    imagesc(X1,Y1,map1);           % loads map
    axis equal                     % equal axis X and Y
    axis image                     % axis adept to image
    caxis ([0 700])               % reach of colours
    colorbar;                     % shows the colourbar
    title( 'HECRAS-Inundation' )
```

Matlab script 3: Creates a view for map1

Strings for resizing maps

```
for r=2:6;
    Yplusb(r) = round((y11(1) - y11(r)) / cellsize(1));
    Xplusl(r) = round((x11(1) - x11(r)) / cellsize(1));
    Xplusr(r) = ncols(r) - ncols(1) - Xplusl(r);
    Yplusu(r) = nrows(r) - nrows(1) - Yplusb(r);
    Rplus(r) = nrows(1) - nrows(r) + Yplusb(r);
    Splus(r) = ncols(1) - ncols(r) + Xplusr(r);
    if Rplus(r) < 0
```

```
Rplus(r)= 0;
end
if Splus(r) < 0
    Splus(r) = 0;
end
end
```

Matlab script 4: Determine differences of map2–map6 with map1

```
if Yplusu(2) > 0                                %
    map2(1:Yplusu(2),:) = [];                  % delete rows (from up)
end                                              %
if Yplusb(2) > 0;                              %
    map2(size(map2,1)-Yplusb(2):size(map2,1),:) = []; % delete rows (from down)
end                                              %
if Xplusl(2) > 0                                %
    map2(:,1:Xplusl(2)) = [];                  % delete columns (from left)
end                                              %
if Xplusr(2) > 0;                              %
    map2(:,size(map2,2)-Xplusr:size(map2,2)) = []; % delete columns (from right)
end                                              %
```

Matlab script 5: Cropping map2 to the sizes of map1

```
nonvalue = -1
for r=1:nrows(1);
    for s=1:ncols(1);
        mapForest(r,s)= nonvalue;
    end
end
```

Matlab script 6: Creating nonvalues for a new map with the size of map1, before the map obtains any data

```
for r=1:size(map2,1);
    for s=1:size(map2,2);
        if map2(r,s) == 4 | map2(r,s) == 5 | map2(r,s) == 10;
            mapForest(r+Rplus(2),s+Splus(2)) = 10;
        end
    end
end
```

Matlab script 7: Creating data in the forest map, obtained from map2, with map2- spatial adjustments

```
for r=2:9;
    if ncols(1) ~= ncols(r)
        display ('unequal number of columns')
        ncols(1)
        ncols(r)
    end
    if nrows(1) ~= nrows(r)
        display ('unequal number of rows')
        nrows(1)
        nrows(r)
    end
end
```

Matlab script 8: Assure that sizes of multiple maps are equal

Implementing functions

```
function damagefactor = factorurban1(x)
if x < 0.5
    damagefactor = 0;
else
    if 0.5 <= x & x < 1.3
        damagefactor = 0.175 + x/4;
    else
        if 1.3 <= x & x < 2.5
            damagefactor = 0.283 + x/6;
        end
    end
end
```

```

else
    if 2.5 <= x & x < 4.5
        damagefactor = 0.49 + 0.08375 * x;
    else
        if 4.5 <= x & x < 8
            damagefactor = 0.719 + 0.033 * x;
        else
            if 8 <= x
                damagefactor = 1;
            end
        end
    end
end
end
end
end
end
return

```

Matlab script 9: Depth-damage curve for urban area defined as a separate function

```

for r=1:nrows(1); % use sizes of inundation map
    for s=1:ncols(1); %
        mapDamage(r,s)= nodatavalue; % create nonvalues DamageMap
        if map1(r,s) > 0; % within inundated area
            mapDamage(r,s)= 0; % initial amount of damage (USD)
            if map4(r,s) == 10 % within map4 area (forest)
                U = factorforest1(map1(r,s)/100) * maxForest; % damage function (in USD/cell)
                mapDamage(r,s)= mapDamage(r,s)+ U; % mapping damage (in USD/cell)
                DamageForest = DamageForest + U; % accumulating damage forest area (USD/cell)
                InundForest = InundForest + 8100; % accumulating inundated forest area (m2)
            end %
        end %
        if (...) % repeat procedure for other land use types
            end %
        end %
    end %
end %
DamageForest = DamageForest * cellArea; % convert USD/cell to USD/m2

```

Matlab script 10: Implementing damage function for forest area

```

D = 0 % initial amount of fatalities
for r=1:nrows(1); % use sizes of inundation map
    for s=1:ncols(1); %
        mapMortality(r,s)= nodatavalue; % create nonvalues MortalityMap
        if map1(r,s) > 0; % within inundated area
            M = factorrapidmortal2(map1(r,s)/100) * (map2(r,s)/1000000*8100); % = factor of fatalities per cell *
            % amount of people per cell
            mapMortality(r,s) = M; % mapping mortality (in people per cell)
            D = D + M; % accumulating number of fatalities
        end
    end
end
end

```

Matlab script 11: Implementing mortality function

Strings for validation

```

% first create initial values for surfaces
for r=1:nrows(1); %
    for s=1:ncols(1); %
        mapSAME(r,s) = nodatavalue; %
        if map1(r,s) > 0; % within the inundated area of map1
            surfaceHR = surfaceHR + 0.0081; % calculate inundated surface
            if map1(r,s) == map2(r,s) %
                mapSAME(r,s) = 10; % map matching inundated surface
                surfaceSAME = surfaceSAME + 0.0081; % accumulate matching inundated surface
            end %
        end %
    end %
    if map2(r,s) > 0; % within the inundated area of map2
        surfaceRI = surfaceRI + 0.0081; % calculate inundated surface
        if map1(r,s) > 0; %

```

```

        surfaceHRinRI = surfaceHRinRI + 0.0081;    % accumulate inundated area map2
    end                                            % within inundated area map1
else                                            %
    if map1(r,s) > 0;                            %
        surfaceHRoutRI = surfaceHRoutRI + 0.0081; % accumulate inundated area map2
        mapOUT(r,s) = 10;                       % outside inundated area map1
    end                                          %
end                                            %
end                                            %
end                                            %
end                                            %

```

Matlab script 12: Spatial comparison: Cropping the inundation map to a line (horizontal)

```

for r=1:nrows(1);
    for s=1:ncols(1);
        if map1(r,s) <= 0
            mapHR(r,s)= nodatavalue;
        else
            if map1(r,s) <= 100
                mapHR(r,s)= 50;
            else
                if map1(r,s) <= 200
                    mapHR(r,s)= 150;
                else
                    if map1(r,s) <= 300
                        mapHR(r,s)= 250;
                    else
                        mapHR(r,s)=400;
                    end
                end
            end
        end
    end
end
end
end

```

Matlab script 13: Qualitative comparison: Separate HEC-RAS inundation map into categories

```

u = 201; % until this row is deleted (inclusive)
v = 203; % from this row is deleted
w = v - u -1; % width of the line
map1(v:nrows(1),:) = []; % delete rows (from down)
map1(1:u,:) = []; % delete rows (from up)
X1 = [0:1:1*ncols(1)]; %
Y1 = [0:1:1* w ]; %
figure(1) %
plot(map1) %

```

Matlab script 14: Depth line comparison: Cropping the inundation map to a line (horizontal)

```

c = 0; % categories c until k, in USD / m2
d = 3; %
(...) % and so on
j = 21; %
k = 9999; %
for r=1:size(map1,1); % use sizes of map 1
    for s=1:size(map1,2); %
        if map1(r,s) > 0 | map2(r,s) > 0 % If this cell has value for at least one
            mapHROB(r,s)= 0.5; % map, value cell in new map 0.5.
        else % if not, give cell a nodatavalue.
            mapHROB(r,s)= nodatavalue; %
        end
        if c <= map1(r,s) & map1(r,s) < d & c <= map2(r,s) & map2(r,s) < d % if cell in two maps is in same
            mapHROB(r,s) = 1; % categorie, value cell 1.
        end
        if d <= map1(r,s) & map1(r,s) < e & d <= map2(r,s) & map2(r,s) < e
            mapHROB(r,s) = 1;
        end
    end
end
(...) % and so on
if i <= map1(r,s) & map1(r,s) < j & i <= map2(r,s) & map2(r,s) < j
    mapHROB(r,s) = 1;
end

```

```
if j <= map1(r,s) & map1(r,s) < k    &    j <= map2(r,s) & map2(r,s) < k
    mapHROB(r,s) = 1;
end
end
end
```

Matlab script 15: Validation map1 with map2 for categories c until k. This validates the quality of the values for desirable categories, it can be used for validation of the damage map