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Flood Damage Assessment with the Help of HEC-FIA Model

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Abstract

Development and urbanization is creating a complicate condition in humans' life. This phenomenon is leading to experiencing a high probability of risk by increasing the level of the vulnerabilities and hazards of/on exposed population. On the other hand the value of the exposed properties has been increasing exponentially and this matter will raise the level of the sensitivity in the financial sectors. In this regard, risk management and risk mitigation should be one of the most important concerns of decision makers, scientists and engineers for developing a sustainable condition.

The focus of this thesis is flood risk; civil protections and authorities have a prominent role in regard of controlling the magnitude of the losses which will be experienced during and after a flood. If we accept the definition of risk as the probability of the damages, the important role of damage estimation and damage prediction for damage mitigation and risk management is understandable. To be more precise, all risk management and risk mitigation policies should be based on an appropriate assessment of the possible damages reduction.

Although human achievements are still crude in many aspects, there are many approaches and efforts in regard of flood damage estimation. In the first step of this research, different aspects and definitions related to the problem of flood damage assessment are reviewed and methods for damage estimation are compared, based on different point of views. In the second step, the behind logics of HEC-FIA (Flood Impact Analysis) software is discussed and the analysis shows that although HEC-FIA considers few approximations in regard of direct damage calculation, it gives many advantages for damage estimation and visualization.

Keywords: Risk, Damage Assessment, Vulnerability, Risk Management, Mitigation Measures, Flood Phenomena

Sommario

Lo sviluppo urbano e l'antropizzazione del territorio hanno posto l'umanità di fronte a nuove sfide. In particolare, il livello di rischio a cui è esposta la popolazione è aumentato considerevolmente, sia a causa di una intensificazione dei fenomeni pericolosi che in conseguenza di un maggior grado di vulnerabilità della popolazione esposta. Da un altro punto di vista, l'aumento esponenziale del valore economico dei beni a rischio ha sollevato l'interesse e la preoccupazione anche del settore finanziario. La gestione e mitigazione del rischio risultano quindi essere un argomento di primaria importanza per uno sviluppo sostenibile del territorio e quindi di notevole interesse tanto per i decisori politici che per i tecnici e gli scienziati .

Il presente lavoro di tesi si concentra sul rischio alluvionale; la protezione civile e le autorità locali hanno in questo caso un ruolo prioritario nel "controllo" dei danni attesi in seguito ad un evento calamitoso. Se si assume il rischio come la probabilità del verificarsi di un certo danno, l'importanza di un'affidabile stima dei danni prima del verificarsi di un evento alluvionale è evidente, tanto per la gestione che la mitigazione del rischio insistente su di un territorio. Nel dettaglio, ogni politica di gestione e mitigazione del rischio alluvionale dovrebbe essere giustificata dalla riduzione del danno attesa.

Sebbene lo stato dell'arte evidenzi alcune lacune, negli ultimi anni la ricerca ha ottenuto significativi risultati nel campo della stima dei danni. Nella prima parte del presente lavoro di tesi verranno analizzate le problematiche inerenti la definizione e modellazione dei danni alluvionali, nonché verranno confrontati tra loro alcuni dei modelli attualmente disponibili per la stima exante. La seconda parte del lavoro è invece focalizzata sull'analisi di HEC-FIA quale strumento informatico a supporto della modellazione dei danni. L'analisi evidenzia che, nonostante alcune approssimazioni nella stima dei danni diretti, i vantaggi nell'uso del software sono significativi tanto per la stima che per la visualizzazione dei risultati.

Keywords: Rischio, Valutazione dei danni, Vulnerabilità, Gestione del rischio, Misure di mitigazione, Alluvione

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Chapter One: Introduction

Development and progress as one of the most important objectives has always been considered in human societies, and reaching new positions and opportunities for improvement and promotion of the quality level of humans' life has been the most crucial and major human effort. In this regard growing urbanization is one phenomenon that leads to a complicated and vulnerable condition with high probability of hazards and it should be optimized with the help of sustainable development. For the urban area with high density of population which is exposed to different types of natural and technological hazards, the possibility of a disaster is high, with human life and property highly vulnerable. The damage costs in human and economic welfare after a disaster have also been increasing, sometimes exponentially. Furthermore, societies are increasingly calling for safety and protection, not only as a consequence of growing fears but also because safety is considered a public good to be guaranteed to citizens. Such demand for risk mitigation can be recognized across both developing and developed countries, though in different forms.

If we consider the definition of risk as the "probability and the magnitude of expected damages that result from interaction between Hazard, Exposure and Vulnerable conditions (UNISDR, 2004)", we can easily understand the prominent role of risk management and risk mitigation in resilience and sustainability. Overall, risk management aimed at decreasing the probability of damage (direct and indirect, tangible and intangible) will be a crucial concern for future decision makers and leaders, managers and planners, or even scientists and engineers.

In peace time and disaster time, it would be a critical stage for decision makers and authorities to reach to an appropriate strategy and policy with the help of damage assessment in regard of mitigating the magnitude of negative consequences. To be more precise, in peace time by distinguishing the level of vulnerability (physical, social and systemic) and the considerable and possible hazards we can perform the damage assessment which leads to establishing some long term or short term risk mitigation measures.

A well prepared emergency plan that could help us in regard of being prepared for optimizing our actions in disaster time is an example of the short term mitigation measure. On the other hand, during disasters we can make initial decisions based on the predicted damages which should be updated dynamically by the help of timely information. All of these issues with the help of the first definition of risk show that our well estimation about possible losses will be important for having optimized policy in regard of decreasing negative consequences and controlling disaster condition.

Scientists have contributed to significant advances in understanding the geophysical causes of natural hazards and in developing sophisticated tools to predict their effect on the humans' life. In contrast, much less attention has been devoted to tools that increase situational awareness and enhance the cognitive abilities of decision makers and first responders. As mentioned before, loss assessment and data collection could be done in **peace time** or **disaster time**. Damage assessment in disaster duration can be performed in three time phases:

- ♣ First Phase, Rapid Assessment: Timing is an important issue in disaster duration and decision makers should act very fast in the first response. The first few hours following a disaster is the period in which key decisions are made about damage assessment (e.g. what is the impacted area and what is the magnitude of the damage) and resource allocation (e.g. deployment of responders, hospitals distribution and capacity, food & water allocation etc.).
- ♣ Second Phase, Early Recovery Assessment: Also this assessment should continue till recovery phase. Without timely information, rescuers lose significant time for important tasks such as evacuation, locating clusters of probable survivors and, more generally, the optimization of response and recovery operations.
- ➡ Third Phase, In-depth Assessment: Furthermore, the results of damage assessment should be updated by doing a field survey after a disaster time.

For achieving this time consuming aims, modeling in a well-organized software and comparison with some forensic data bases related to recent extreme events will be an appropriate methodology for damage assessment and risk management. In other words, different situations compare to the predicted scenarios that could be the consequence of complicate phenomena, uncertainty in information and multiple sources of data, will affect normal procedure of the damage assessment. In this way, using the technology can support us for having an advanced decision-support system during peace besides having an accurate awareness of the current situation in disaster duration to refine the decisions continuously over time for disaster management and performing operational actions to mitigate the consequences.

HEC-FIA (Flood Impact Analysis) due to well connection with hydraulics software, having flexible properties and well visualization with the help of Geographic Information System (GIS) could be an appropriate choice for modeling and assessing the level of the damages in flood scenarios. The objective in this study is related to evaluating these features.

Overall, it is worth noting that damage assessment with the help of an appropriate tools will help us for having an accurate prediction of the next disasters and we can provide significant improvement in our future emergency plans by decreasing the level of the uncertainty and it could be important factor for improving the resilience stage of the response in one society. In addition to decision makers and civil protections, organizations that usually will use these results are insurance and re-insurance companies. As I mentioned before, by increasing the level of urbanization these organizations are too sensitive about the possible expenses related to disasters. Then a good estimation about future disasters will help them to handle critical situations better.

In the first step of this research, we will discuss about different classifications and definitions in the area of damage assessment. Next, in the template of state of art, we will study and compare some available models in three separate aspects of input data, flood damage model and damage calculation. In the third step, we will discuss about available classifications in direct monetary damage assessment and we will investigate the available gaps and uncertainties in the area of knowledge. Finally, we will study the behind logics of HEC-FIA software which will be helpful in regard of distinguishing pros on cons of using this software in flood damage assessment.

Chapter Two: Damages Presentation and State of Art

1. Damage Definition

All over the world, floods represent major threats for people living in river or coastal flood plains (*Torterotot*, 1993) and over the past few decades the economic damage as a result of flooding has increased in most regions. Several studies state that most of this increase can be attributed to a growth of exposed population and wealth to flood phenomena (*Barredo*, 2009; *Bouwer et al.*, 2010; *Kreft*, 2011; *UNISDR*, 2011; *Barredo et al.*, 2012).

If we note that flood risk can be defined as the probability and the magnitude of expected losses that result from interactions between flood hazard and vulnerable conditions (UNISDR, 2004), then losses assessment could be considered as the essential part of risk mitigation (Elmer et al, 2010). In the area of natural hazard management, and especially in flood risk management, damage assessments in terms of economic losses are gaining importance, in order to be able to carry out cost-benefit analyses in support of the decision-making process on flood mitigation measures, as well as in financial appraisals and risk prediction required by the insurance and reinsurance sector (Merz et al., 2010). Overall, the estimation of flood damage is an important component for risk mapping, optimal decision of flood mitigation measures, financial appraisals for insurance sectors and comparative risk analyses (Kreibich et al., 2010).

Types of damage are typically differentiated into **direct and indirect** damages, which may be **tangible or intangible** (e.g. Parker et al., 1987; Messner et al., 2007; Meyer et al., 2012). Direct damage is caused directly by the physical processes of the hazard (e.g. damages of structures and inventories); while indirect ones are caused by the impact of the first category (e.g. costs occurring at a longer period of time or a larger spatial scale to the disaster itself). They can occur inside or outside of the hazard area and often with a time lag.

The difference between tangible and intangible damages is that the first can be valuated from a financial point of view (all marketable goods and services), whereas the second cannot be assessed from a monetary point of view, e.g. loss of life, damage to ecosystems (Andr'e et al, 2013).

In addition, risk mitigation costs can be regarded as part of the total cost of natural hazards and are thus considered an essential loss category (*Bouwer et al., 2011*). The costs of risk mitigation can also be classified according to the loss categories introduced above, i.e. direct, indirect and intangible losses. The direct losses of risk mitigation refer to any losses attributed to research and design, the set-up, operation and maintenance of infrastructure, or other measures for the purposes of mitigating (or adapting to) natural hazards. The indirect losses of risk mitigation relate to any secondary losses (externalities) occurring in economic activities/sectors (or localities) that are not directly linked to such infrastructure investment. The intangible losses refer to any non-market health or environmental impacts of risk mitigation measures, such as environmental damage due to the development of mitigate infrastructure or a change in agricultural practices (*Meyer et al., 2013*).

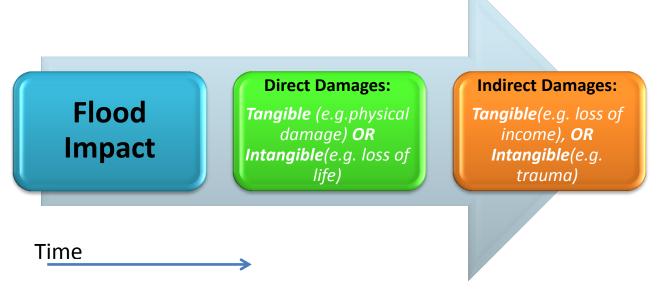


Figure 1.Process of the Impact and Damages

It is worth mentioning that most studies are focused on direct-tangible damages and the assessment of indirect and intangible losses, while very important, remains methodologically difficult and because of this reason the application of damage assessments in practice is often incomplete and biased. Furthermore, all parts of damage assessment entail considerable uncertainties due to insufficient or highly aggregated data sources, along with a lack of knowledge about the processes leading to damage(Elmer et al., 2010; Meyer et al., 2012). While much effort is done to improve the hazard estimation leading to more accurate and more reliable models, the estimation of flood damage is still crude and affected by large uncertainties (Merz et al., 2004; Egorova et al., 2008; Freni et al., 2010; de Moel and Aerts, 2011; Meyer et al., 2013). According to Apel et al. (2009) and de Moel and Aerts (2011), the largest impact on damage estimation is caused by the shape of the applied models as well as the associated asset values, while the accuracy of the hydraulic input is of minor importance.

Flood consequences are generally measured by the exposure of elements at risk and their vulnerability, often expressed in monetary terms (*Thywissen, 2006*). In the above process, to relate the impact and vulnerability parameters to the loss, **absolute or relative** loss functions can be used.

2. State of Art on Flood Damage Assessment

2.1. <u>Different Approaches</u>

There are two general approaches for economic damage assessment as **expost** and **ex-ant**. Ex-post assessments are carried out in the aftermath of the disaster for emergency management or the coordination of early recovery issues, or later, for feedback on experience concerning damage processes and costs (*APFM*, 2007). Also, It will be used to inform local or national governments of the overall amount of induced damage and to provide a basis for calculating levels of compensation and recovery support (e.g. S"achsische Staatskanzlei, 2003; McCarty and Smith, 2005; Karunasena and Rameezdeen, 2010).

Ex-ante assessments, i.e. prior-event, aim to evaluate potential economic losses for scenarios having probable hazard characteristics. Ex-ante assessment models are generally calibrated with damage data from ex-post assessments. However, most economic analysis guidelines mainly address ex-ante assessments, since ex-post assessments are not as well developed. For ex-ante damage assessment purposes, a standard approach calls on damage functions, also referred to as **stage-damage curves or fragility curves** (*Messner et al., 2007*). These functions define the causal relationship between the intensity of hazard parameters and a level of damage or loss for each class of assets. As mentioned before, they can be expressed in terms of absolute values of estimated costs or in relative damage in order to support governmental decision making relating to alternative risk mitigation options.

Furthermore, we can categorize the available approaches to synthetic methods and empirical ones. While synthetic approaches rely on expert judgment, empirical approaches use damage data derived from ex-post assessments of actual past events. While the first method appears more theoretical, the second calls for a substantial effort in collecting ex-post damage information, and such datasets are scarce.

♣ The focus of this dissertation, as will be shown precisely, is on ex-ante approach for direct tangible damages.

	Advantages	Disadvantages	
Relative Damage Functions	 Better transferability in space and time, since they are independent of changes in market values (Krzysztofowicz and Davis, 1983). Applicable for different purposes 	Values of the object assets are necessary. Their estimation might bring in uncertainty.	
Absolute Damage Functions	No need for asset values, the estimated monetary damage due to a given flood scenario results directly.	Need for regular re-calibration because of depending on the total value of the affected object	

Advantages and disadvantages of empirical and synthetic flood damage models

	Advantages	Disadvantages
Empirical Damage Models	 Real damage information is more accurate than synthetic data Effects of damage mitigation measures can be quantified and taken into account in damage modeling 	 Detailed damage surveys after floods are uncommon, so that models may be based on poor quality data Due to lack of damage records related to floods with high water depth, extrapolations is required Transferability in time and space is difficult due to differences in warning time, flood experience, building type and contents
Synthetic Damage Models	 In each building, in dependent from experienced floods, damage information for various water levels can be retrieved Approach does not rely on information from actual flood events and can therefore be applied to any area Higher level of comparability of damage estimates 	 High effort is necessary to develop detailed data bases What-if analyses are subjective, resulting in uncertain damage estimates Mitigation actions are not taken into account

Figure 2.Advantages and Disadvantages of Different Functions

2.2. Spatial Scales

Flood damage assessments are performed on different spatial scales:

- ♣ Micro-scale: the assessment is based on single elements at risk. For instance, in order to estimate the damage to a community in case of a certain flood scenario, damages are calculated for each affected object (building, infrastructure object, etc.).
- ♣ Meso-scale: the assessment is based on spatial aggregations. Typical aggregation units are land use units, e.g. residential areas, or administrative units, e.g. zip code areas. Their size is in the order of magnitude of 1 ha to 1 km2 (*Preference of reinsurance companies*).
- ♣ Macro-scale: large-scale spatial units are the basis for damage estimation. Typically, administrative units are used, e.g. municipalities, regions, countries.

Depending on the precision needed for the assessment and the spatial scale of the analysis, damage functions can be based on land-use category areas (*meso-and macro-scale*) or on individual objects (*micro-scale*) (*Merz et al., 2010*). At the macro-scale (*regional to national level*), the data available, allowed an overall synthesis to be made of flood impacts. However, it does not describe damage circumstances, nor hazard characteristics, and does not, in itself, allow a direct link to be established between costs and damage types. At a micro-scale(*local studies*), the detailed information on types and costs of damage based on loss adjustment reports allowed a typology of damages and damage processes to be defined, and the costs to be divided between distinct construction works.

2.3. Flood Damage Models

Well-known flood damage models developed for simulating ex-ante flood damage can be listed as bellow:

- FLEMO (Germany)
- Damage Scanner (The Netherlands)
- ♣ Rhine Atlas (Rhine basin)
- The Flemish Model (Belgium)
- ♣ Multi-Coloured Manual (United Kingdom)
- HAZUSMH (United States)
- ♣ The JRC Model (European Commission/ HKV)

Also, these models could be compared on **three** main aspects:

- Input Data
 - √ Hydrological
 - ✓ Data Method
 - ✓ Number of Classes
- Scale
 - ✓ Spatial Scale
 - ✓ Unit of Analysis
- Damage calculation
 - ✓ Cost Base
 - ✓ Empirical Validation
 - ✓ Damage Functions

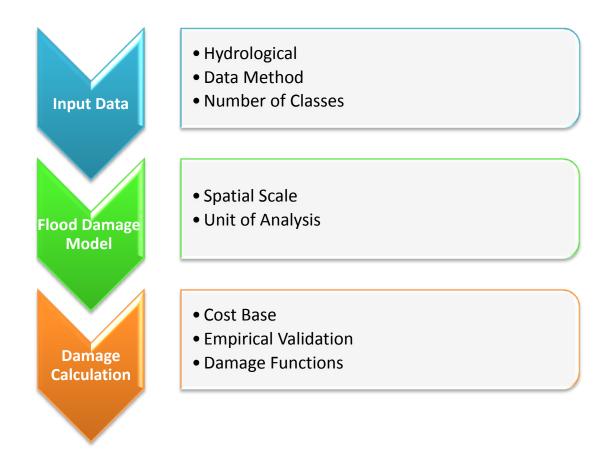


Figure 3.Main Aspects of Damage Models

Before comparing the different flood damage models, in addition to Spatial Scale which is discussed before following aspect are notable as well:

2.3.1 Input Data

Generally, Most of the modeles still consider the inundation depth as the main impact parameter (see e.g Merz et al., 2010; Jongman et al., 2012 for an overview), but some models also integrate additional parameters like flow velocity (e.g. Schwarz and Maiwald, 2007; Kreibich et al., 2009; Pistrika and Jonkman, 2010), contamination (e.g. Kreibich and Thieken, 2008; Thieken et al., 2008; Prettenthaler et al., 2010), the duration of flooding (e.g. Dutta et al., 2003; Penning-Rowsell et al., 2005) or the recurrence interval (e.g. Elmer et al., 2010). With regard to the consideration of different vulnerability parameters, the majority of damage models differentiates between the use or type of building (e.g. Oliveri and Santoro, 2000; Dutta et al., 2003; Kang et al., 2005; Büchele et al., 2006; Schwarz and Maiwald, 2007; Kreibich and Thieken, 2008; Thieken et al., 2008). Few models also take additional parameters like precautionary behavior (e.g. Büchele et al., 2006; Kreibich and Thieken, 2008; Thieken et al., 2008) or the early warning time (e.g. Penning-Rowsell et al., 2005) into account.

2.3.2. Damage Calculation

In this regard considering the cost base or the type of values on which the maximum damage per object or land use class will be calculated will be important. This value can be expressed as either **replacement** cost or **depreciated/repair** cost. Replacement costs represent total expected monetary flows while depreciated costs express real economic loss (e.g. ICPR, 1998; Penning-Rowsell et al., 2010). Also empirical validation or the validation of the damage model after development on the basis of reported flood damage data could be an important parameter (refer to ex-post and ex-ant explanations).

Furthermore, the type of depth–damage function, which can represent either the **relative** percentage loss with respect to a pre-defined maximum damage value or the **absolute** monetary loss with depth, should be considered.

2.3.3. Flood Damage Models

↓ FLEMO: The FLEMO model family has been developed at the German Research Centre for Geosciences, mainly for flood risk analyses from the local to national scale and for the estimation of direct tangible damage (e.g. Apel et al., 2009; Vorogushyn et al., 2012).

Estimation Model for the private sector (FLEMOps) and the rules for Flood Loss Estimation Model for the commercial sector (FLEMOcs) (Kreibich et al., 2010; Seifert et al., 2010a). FLEMOps calculates the flood damage using five different classes of inundation depth, three individual building types, two classes of building quality, three classes of contamination and three classes of private precaution (Thieken et al., 2008). FLEMOcs has a similar structure, it calculates the flood damage using five classes of inundation depth, four different economic sectors, three classes of company size in respect to the number of employees as well as three classes of contamination and three classes of private precaution (Kreibich et al., 2010).

The models have been intensively validated on the micro- as well as on the meso-scale using different data sets of repair costs at the scale of single buildings and whole municipalities (*Thieken et al., 2008; Seifert et al., 2010a*).

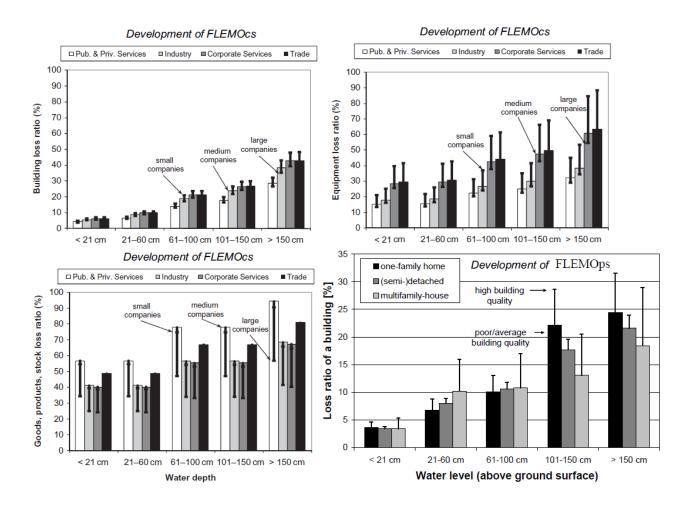


Figure 4.FLEMO Model Figures

■ Damage Scanner: The Damage Scanner is based on the economic values and depth—damage curves of the HIS-SSM module (*The standard method for the detailed estimation of flood damage in the Netherlands*), but as opposed to HIS-SSM works with aggregated land use data instead of individual units. The Damage Scanner has been used for the estimation of future flood risk under climate and land use changes and is mainly based on synthetic data, using "what-if analyses" estimating the damage that would be expected in case of a certain flood situation. Maximum damage values are based on replacement values. Indirect losses are calculated as an additional 5% on top of the direct losses, and are consequently also subject to depth—damage curves.

- **The Flemish:** A model for flood damage estimation developed for the Flemish Environmental Agency in Belgium is described by Vanneuville et al. (2006). Similar to the Damage Scanner, the Flemish methodology is specifically designed for assessments on a regional and national scale using aggregated land use data. The methodology has been applied for identifying vulnerable areas (Vanderkrimpen et al., 2009) and calculating efficient flood defense investments (Giron et al., 2010). The maximum damage values in the Flemish model are based on national averages of housing prices, surface areas and market values. Damage to residential content is assumed to be 50% of the structural losses. Furthermore, indirect costs are included as a percentage on top of the direct damage, ranging from 10% for agriculture to 40% for industry. The Flemish model has a separate structure and content class for residential areas and there is only one infrastructure and one industry (industry plus commerce) class. Also, the same as Damage Scanner it has been used for the estimation of future flood risk mainly based on synthetic data.
- **HAZUS-MH:** The HAZUS Multi-Hazard software (*FEMA, 2009;* Scawthorn, 2006) is a tool for the estimation of the potential economic, financial and societal effects of natural hazards within the United States. HAZUS-MH besides flood includes wind and earthquake hazards as well. The typical scales of application are city, county and state level. Over several years, all inputs required for flood damage estimation such as: building data on the census block level (including building type, number of floors, presence of a basement and date of construction), data on an object level of infrastructure and high-potential facilities (e.g. hospitals), a large number of nationally applicable depth-damage functions for buildings on the basis of empirical damage data(as well as separate functions developed by USACE for specific regions of the United States) and a separate user-defined module for the estimation of indirect costs and larger economic effects of the flood event, were collected in the software. Users of the HAZUS software have to choose the level of analysis (vary from using default input data to extensive additional economic and engineering studies).

Also, the user can define the intensity and timing of the flood, early warning system and whether the losses should be calculated on the basis of replacement or depreciated asset values.

- ♣ Multi-Coloured Manual: The Multi-Coloured Manual (MCM) is the most advanced method for flood damage estimation within Europe (e.g. Penning-Rowsell and Chatterton, 1977; Penning-Rowsell et al., 1992, 2010). The purpose of the MCM is explicitly defined for water support management policy and assessment of the investment decisions (Penning-Rowsell et al., 2010, p. 1). For these purposes, Penning-Rowsell et al. (2010) have developed a wide range of depthdamage relationships and additional methodologies for the estimation of the absolute losses value of flooding. These relationships are developed for a wide variety of residential, commercial and industrial buildings, using mostly synthetic analysis and expert judgment. For each damage class, damage curves are available for different levels of maintenance and the presence of a basement. Similar to HAZUS, the MCM is an object-based model that the maximum damage per square meter estimates only reflects expected repair costs to buildings and not damage to the surrounding land.
- Rhine Atlas: In order to meet the performance targets in terms of risk reduction and flood awareness, the Rhine Atlas damage model (RAM) was developed (ICPR, 2001). The RAM has the least detailed classification system of the models included in this study by recognizing only five land use classes. The depth—damage functions and the corresponding maximum damage values were established on the basis of the empirical results and expert judgment (ICPR, 2001). For the land use classes, residential, industrial and infrastructure, the RAM applies both a structure and contents damage assessment. Since the RAM is developed to estimate direct economic costs, all damage values are calculated on the basis of depreciated values. Through a comparison with insurance data, the ICPR (2001) estimates that the replacement values are approximately a factor 2 higher than depreciated values. Indirect losses are not included in the RAM method.

→ JRC Model: In support of European policy on flood risk management, the European Commission's Joint Research Centre — Institute for Environment and Sustainability (JRC-IES) has developed a JRC damage model (*Huizinga*, 2007), which has been applied to estimate trends in European flood risk under climate change (*Ciscar et al.*, 2011; Feyen et al., 2011). The JRC Model comprises differentiated relative depth—damage functions and maximum damage values for all EU-27 countries. Properties are classified for five damage classes: residential, commercial, industrial, roads and agriculture. As a result, the flood depth in every grid cell is multiplied with a weighted average of relative depth—damage functions and maximum damage values.

2.3.4. Flood Damage Models Comparison

Based on the mentioned issues, following table summarize the characteristic of flood damage models in three separate aspects (*Input Data, Damage Model, and Damage Calculation*). In this regard, it would be worth noting that:

- ♣ For estimating the direct flood losses, except HAZUS model which consider duration, velocity, debris, rate of rise and timing, rest methods as discussed before use only depth as the hydrological input.
- Damage functions in most of the methods are relative.
- These models are still crude in estimating the indirect consequences and they mostly have focused on **direct physical damages**.
- Except HAZUS model, they are not well flexible in cost base expression.
- Unit of analysis in most of the models is considered as the surface area of the objects.

Flood Damage Model		Input Data			Damage Calculation			
Damage Model	Spatial Scale	Unit of Analysis	Hydrological	Data Method	No. of Classes	Cost Base	Empirical Validation	Damage Functions
FLEMO	Local Regional National	Surface Area	Depth Contamination	Empirical	5-10	Replacement values	Yes	Relative
Damage Scanner	Regional National	Surface Area	Depth	Synthetic	5-10	Replacement values	No	Relative
Flemish Model	Regional National	Surface Area	Depth	Synthetic	5-10	Replacement values	No	Relative
HAZUS- MH	Local Regional	Individual Objects & Surface Area	Depth, Duration Velocity, Debris Rate of rise Timing	Empirical Synthetic	>20	User's Choice	Yes	Relative
МСМ	Local Regional	Individual Objects	Depth	Synthetic	>20	Depreciated values	Limited	Absolute
Rhine Atlas	Local Regional	Surface Area	Depth	Empirical Synthetic	10-20	Depreciated values	No	Relative
JRC Model	Regional National European	Surface Area	Depth	Empirical Synthetic	5-10	Average Values	No	Relative

Figure 5.Flood Damage Models Comparison

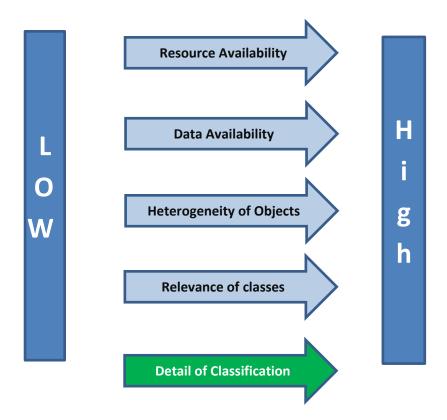
3. <u>Direct Monetary Damages</u>

According to available models, the overall procedure for calculating the direct economic damages at micro scale can be categorized to bellow steps:

- First, we obtain the "**inundation map**", which provides flood depth extension for the inundated zones of the study area.
- ♣ Second, we construct consistent "land use maps" for the maximum inundated area.
- ♣ Third, we will do the exposure analysis and asset assessment by describing the number and type of elements at risk and by estimating their asset value.
- Fourth, in regard of vulnerability identification, element which are exposed to hazard will be categorized into homogenous classes.
- ♣ Finally, by means of input data related to the stage of the Hazard (i.e. water depth, duration and speed, waves shocks and scour, flood frequency etc.), Vulnerability (i.e. number of story's, building type, surface area, presence of basement, construction materials, quality of building, precaution etc.), Exposure and with the help of damage curves, ex-ante direct damages will be assessed in relative or absolute values.

3.1. Classification of Elements at Risk

Depending on the spatial extent of the investigated inundation_area and the chosen degree of detail of the damage assessment, a large number of elements at risk have to be considered. In general, it is not possible to assess the damage for each single object, because there is no information on the damage behavior of each object and/or because such a detailed assessment would require a huge effort. Therefore, elements at risk are pooled into classes, and the damage assessment is performed for the different classes, whereas all elements within one class are treated in the same way. For example, in the assessment of flood damage to private households, all households of a certain type may be grouped in one class and may obtain the same asset value, e.g. related to the floor area. Similarly, the relative damage of all households in this class may be estimated by using the same susceptibility function.



In most cases the classification is based on economic sectors, such as **private** households, companies, manufacturing, public sectors, infrastructure, cultural heritage, strategic buildings and agriculture, with a further distinction into sub-classes. This is based on the understanding that different economic sectors show different characteristics concerning assets and susceptibility. Furthermore, a pragmatic reason for using economic sectors as classification criterion is that economic data which are needed for estimating the value of elements at risks are usually aggregated according to economic sectors. To be more precise, the elements at risk within one economic sector may be very diverse. Therefore, most damage assessments introduce sub-classes. For example, recently in Germany the damage models FLEMOps and FLEMOcs have been developed for the private and the commercial sector, respectively (Thieken et al., 2008; Kreibich et al., 2010). FLEMOps, the model for the private sector, differentiates into three building type classes (one-family homes, semi-*)detached houses, multi-family houses)* and two building quality classes (low/medium quality, high quality).

Similarly, FLEMOcs distinguishes among three classes concerning company size in respect to the number of employees (1- 10, 11-100, >100 employees) and among four sub-sectors (public and private services, producing industry, corporate services, trade). Even with such sub-classes the variability of objects within one sub-class is large. Therefore, asset estimates and damage functions that are given for a certain sub-class are expected to describe only a rather limited share of the variability that is observed in damage data. However, finer classifications require more data and/or information which are usually not available. Also, based on the objective classifications which are related to vulnerability of the structures, the effective aspects of the hazard could vary as well. For instance, flood impact (i.e. Inundation depth, Flow velocity, Duration of inundation, Contamination, Sediment, Rate of rise, Frequency of inundation and Timing) varies between different sectors. Flood damage to residential buildings is strongly dependent on the water depth of a flood, whereas for damage to agricultural crops the time of flooding and the duration of the flood are important (F"orster et al., 2008). This idea related to different hazard (flood) impacts for different classifications is visualized in the bellow hydro-graph and also it will be extended in the **next chapter**.

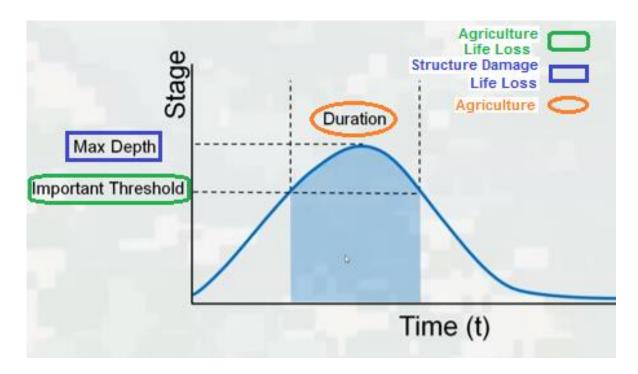


Figure 6. Hydrograph Data for Different classification

3.1.1 <u>Examples for Different Economic Sectors and Models</u> <u>Comparison</u>

Residential Sector: Most flood damage data, analyses as well as damage models refer to the residential sector. Here, only three models are presented exemplarily to illustrate different development strategies, function types and number of parameters. As it has shown in the bellow table, the model of the Multicoloured Manual for UK is based on synthetic damage data and uses absolute damage functions (Penning-Rowsell et al., 2005). In contrast, FLEMOps is based on empirical damage data and uses relative damage functions (B"uchele et al., 2006; Thieken et al., 2008). The relative damage model of the ICPR is based on a combination of empirical and synthetic damage data (ICPR, 2001). The models differ greatly in the number of influencing parameters used. The model of the ICPR exclusively takes the water depth into account to estimate the immobile and equipment damage of settlements. The model of the Multicoloured Manual takes into account 14 water depth levels and two duration classes (Penning-Rowsell et al., 2005). Also, five house types, seven building periods and four different social classes of the residence' occupants are considered. FLEMOps differentiates between five water depth classes, three contamination classes, three building types, two building qualities and three precaution classes (B"uchele et al., 2006; Thieken et al., 2008).

Models	Country	Data Method	Functions	Input Parameters	Damage Type
Multicoloured	UK	Synthetic	Absolute	Water depth, flood duration, building type, building age social class of the occupants	Building fabric items, household inventory
FLEMOps	Germany	Empirical	Relative	Water depth, contamination, building type, quality of building, precaution	Building and contents
ICPR	Germany	Empirical- Synthetic	Relative	Water depth	Immobile, equipment, mobile

Figure 7. Models Comparison for Residential Sectors

Industrial Sector: Models for the estimation of direct damages of companies differ based on their development, their functions, the parameters they include and the damage types they estimate. In regard of comparing models, while the HAZUS-MH distinguishes 16 main company types with several sub-classes for damages to buildings, RAM (NRE, 2000), which is a model of Australia that calculate damages in absolute values and express it in total for all asset types, does only differentiate in companies smaller or larger than 1000m2. Variations between the models can also be found regarding the company size as resistance parameter. HAZUS-MH includes a size factor in its object classification (e.g. small, medium, large warehouses), Anuflood which is another Australian models and it is almost the same as RAM, relates company size to the building floor space and FLEMOcs distinguishes three sizes of companies in relation to their number of employees (Kreibich et al., 2010).

Also, some models separately estimate damages to different asset types, e.g. the functions developed by the USACE, which are partly used in HAZUS-MH (*FEMA*, 2003; Scawthorn et al., 2006), distinguish damages at buildings, inventory and equipment. FLEMOcs distinguishes damages at buildings, equipment and goods, products, stock (*Kreibich et al.*, 2010), and the ICPR (2001) and the Saxon Agency of Environment and Geology (*LfUG*, 2005) estimate separately damages to buildings, immobile inventory and mobile inventory. Other models, e.g. Hydrotec (*Emschergenossenschaft and Hydrotec*, 2004) the same as Anuflood (*NR&M*, 2002) and RAM (*NRE*, 2000), simply estimate the total damage of all asset types.

Models	Country	Data Method	Functions	Input Parameters	Loss Type
Anuflood	Australia	Empirical	Absolute	water depth, object size, object susceptibility	total
RAM	Australia	Empirical/ Synthetic	Absolute	object size, object value, lead time, flood experience	total
FLEMOcs	Germany	Empirical	Relative	water depth, contamination, business sector, number of employees, precaution	building and equipment and goods, products, stock
MURL	Germany	Empirical	Relative	water depth, business sector	building and inventory
Hydrotec	Germany	Empirical	Relative	water depth, business sector	total
LfUG	Germany	Empirical/ Synthetic	Relative	water depth <i>or</i> specific discharge, business sector	building and mobile and immobile inventory
Multicolo ured	UK	Synthetic	Absolute	water depth, flood duration, object type, lead time	total
HAZUS- MH	USA	Empirical/ Synthetic	Relative	water depth, object type	building and equipment and inventory

Figure 8.Models Comparison for Industrial Sectors

- Infrastructure: Damage to infrastructure includes a variety of potentially affected structures and different damage types. Potentially affected structures are public utilities (lifelines) such as water supply, sewerage and drainage, gas and power supply and telecommunication. Furthermore, damage to transportation facilities, particularly roads and railways, belong to this damage sector. Also, sometimes essential facilities such as hospitals, schools and fire brigades are considered in this sector as well. Besides direct damage to the affected structures damages can occur due to a disruption of services, which have to be considered as indirect damage. Damage due to disruption of utilities is in general a function of physical and systemic (redundancy, transferability, interdependency) vulnerability of the flooded structures and networks. With regard to damage to infrastructure, only few data and no well-established models exist. Since damage is governed by many local factors, uncertainties are very high (Dutta et al., 2003). Penning-Rowsell et al. (2005) further recommend using the depthdamage approach for assessing direct damage. However, due to the site-specificity of utility works, no standard data are given in the Multicoloured Manual. It is worth noting that in contrast to other sectors direct damage to transportation infrastructure seems to be more influenced by flow velocity than by inundation depth (Kreibich et al., 2009). Consequently, effects by erosion and debris flow (closure of bridges) have to receive more attention. Due to the variety of structures a three-step filtering process has been proposed with Multicoloured Manual.
 - ✓ Count relevant infrastructure assets at risk by assessing their sizes (e.g. length) and values
 - ✓ assess the total risk for each infrastructure by roughly classifying the likelihood of damage and the scale of impact as high, medium or low,
 - ✓ quantify damages for "high risk" and "very high risk" assets only Similarly, in HAZUS-MH important lifeline components are selected for fragility modeling. Impacts to system functionality, relative cost of the component and the overall time to recover from damage are considered, as well (*Scawthorn et al., 2006*).

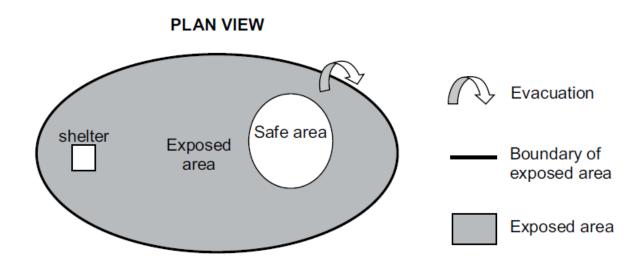
Agricultural sector: Flood damage in the agricultural sector includes losses of agriculture products, farm houses and farm infrastructure (Dutta et al., 2003). The reduction in yield and quality of agriculture products may require additional expenditure for sowing, tillage, and the application of fertilizer and crop protective agents. Additionally, damage to the soil that refers to a potential decrease in the quality of soil and a loss of soil structure due to compaction or erosion might be relevant as well (Pivot et al., 2002). Total economic damages in the agricultural sector are frequently much lower than those in urban areas. Hence, damage evaluation is often neglected or only accounted for by using simple approaches and rough estimates (F"orster et al., 2008). A significant difference for damage evaluating compare to other sectors is the importance of the time of occurrence of a flood with respect to crop growth stages and critical field operations (Penning-Rowsell et al., 2003). For example, flooding in July results in much higher damages for summer grain crops just prior to harvesting than flooding in August just after harvesting. In most models, as opposed to other flood variables, time of occurrence is considered.

Models	Country	Data Method	Functions	Parameters
Citeau	France Synthetic		Relative	Water depth, flood duration, flow velocity, submersion period, crop type
Neubert and Thiel	Germany	Synthetic	Relative	Submersion period
MEDIS-Model	Germany	Empirical- Synthetic	Relative	Flood duration, submersion period, crop type
LfUG	Germany	Empirical- Synthetic	Relative	Specific discharge
Dutta et al.	Japan	Empirical	Relative	Water depth, flood duration, submersion period, crop type
Hoes and Schuurmans	The Netherlands	Synthetic	Relative	Water depth

Figure 9.Models Comparison for Agriculture Sectors

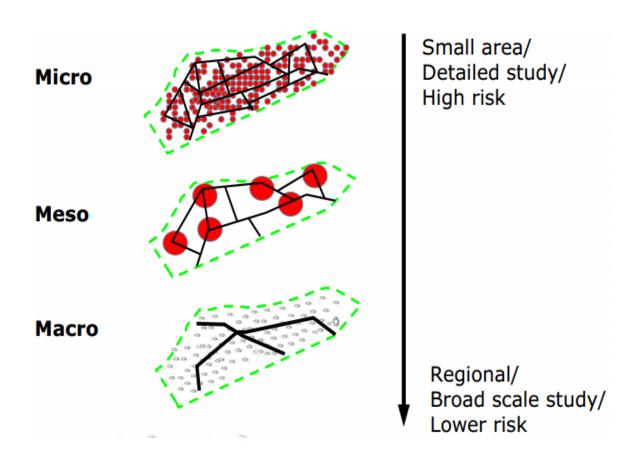
4. Loss of Life Estimation

In this section we will study a general approach for the estimation of loss of life. In order to estimate loss of life it is often necessary to analyze the number of **people exposed** and the effects of **evacuation**, **shelter** and **rescue**. The actually **exposed population** involves all people exposed to the physical effects of the disaster. The number of people exposed can be deduced from the population affected by taking into account the effects of evacuation, shelter, rescue and escape. **Evacuation** is defined as: "the movement of people from a (potentially) exposed area to a safe location outside that area before they come into contact with physical effects". Within the area people may find protection within **shelters**. These are constructed facilities in the exposed area, which offer protection. **Escape** refers to the movement of people by themselves through the exposed area and **rescue** concerns the removal of people by others from an exposed area. Rescue and escape only prevent loss of life if people are rescued or escape before they will lose their life due to exposure.

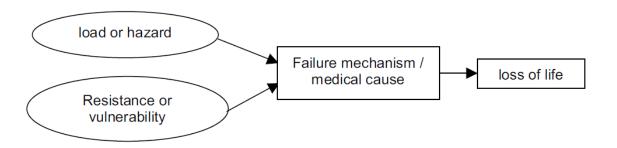


Also, loss of life modelling can be performed at different levels of detail:

- ♣ Individual Level (Micro Scale): By accounting for individual circumstances and behavior it is attempted to estimate the individual probability of death and evacuation routs will be modeled by detail for each person.
- ♣ Group or Zone Level (Meso Scale): Groups of people, locations or zones with comparable circumstances are distinguished and mortality is estimated for these groups / zones and the simplified evacuation routs are used in this method.
- ♣ Overall Event Level (Macro Scale): One mortality fraction is applied to the exposed population as a whole and the evacuation time will be calculated based on average distance to safety.



In the reporting and analysis of fatalities due to disasters a distinction is often made between fatalities caused by either the direct or indirect exposure to the event (*Combs et al. 1999*). Directly related deaths are those caused by the physical effects of the event (*bellow figure*). Indirectly related deaths are those caused by unsafe or unhealthy conditions that occur because of the occurrence of the disaster.



Overall and based on the mentioned issues necessary for loss of life estimation, we can categorized related approaches into following steps:

- ♣ The assessment of physical affected area associated with the critical event, including the dispersion of the effects and the extent of the exposed area;
- ♣ Determination of the number of people exposed in the exposed area, taking into account the scale and level of detail, initial population at risk and the possibilities for evacuation, shelter, escape and rescue;
- ♣ Estimation of the fatality and loss of life amongst the exposed population, taking into account the extent of physical effects and the number of people exposed.
- ♣ In the next chapter, we have discussed these steps precisely with the help of LIFESim method.

5. Knowledge Gaps and Uncertainties

By considering the discussed issues in the state-of-the-art section, in this part we will focus on the remaining knowledge gaps in the area of damage assessment. The most important knowledge gaps could be named as bellow and will be discussed in the next parts:

- Problems relating to the incompleteness and uncertainty of cost assessments
- The lack of sufficient and reliable data
- Shortcomings of existing methods
- ♣ The future dynamics of risk

5.1. <u>Uncertainty</u>

The review of existing methods and practices relating to damage assessments for natural hazards shows that there is a strong focus on the direct damages of natural hazards. By contrast, business interruption costs, intangible costs and especially indirect costs are often underestimated or even neglected entirely (cf. Handmer, 2003; Meyer et al., 2009; Lequeux and Ciavola, 2011; Pfurtscheller et al., 2011). This may lead to incomplete cost estimates and risk management decisions which are only based on the mitigation of directtangible losses. Additionally, major uncertainties still remain in all parts of cost assessments (Function uncertainty and Value uncertainty). They are related to inadequate or aggregated data sources, a lack of knowledge about the processes leading to damage and the resulting lack of appropriate models for developing a causal relationship between costs and hazard parameters. Also, damage modeling aims at predicting damages of potential future events and models have to be transferred to another situation. These transfers can be grouped into transfer between elements at risks, time, space, and spatial scale. Each transfer is associated with uncertainty. Although improvements have been made over the last few decades, considerable uncertainties still exist in all parts of cost assessments. In any appraisal it is therefore important to identify the main sources of uncertainty at an early stage and try to reduce or handle them. Any residual uncertainties in cost estimates should be documented and communicated to decision makers.

5.2. Lack of Sufficient and Reliable Data

As outlined above, one of the main sources of uncertainty in cost assessments for natural hazards is the lack of sufficient, detailed, comparable and reliable data (*Handmer*, 2003). Improvements can be made with regard to

- ♣ The availability of input data sources for ex-ante cost estimations: primary data collection, i.e. original surveys, may be an option for closing such data gaps, although it would be costly and time-consuming.
- ♣ The collection of ex-post event data: ex-post event data on damage or loss is needed to better understand the processes that cause damage, to identify the most important factors influencing damage, and to develop, calibrate and validate models.

5.3. Shortcomings of existing methods

Another source of uncertainty in cost assessments are shortcomings in existing methods. One knowledge gap that affects many existing damage models is that they are often not validated. However, such validations are needed in order to determine the accuracy of cost assessments (*Bubeck and Kreibich, 2011*). Validations such as those described by Kirwan (1997) may ideally use comparisons between predicted damages and observations (*absolute validation*). However, other ways of assessing the validity of damage models are also possible. These include the use of expert knowledge, comparisons of alternative damage models, and methods for evaluating the process of model construction.

Overall, data validation should be done in all aspects of damages such as direct costs and business interruption costs, indirect costs, intangible (non-market) costs and costs of risk mitigation.

5.4. The future dynamics of risk

Natural hazard risks are essentially dynamic, depending on climate variability as well as on changes in vulnerability patterns (*IPCC*, 2012). Risks and their associated costs will continue to change in the future due to the dynamics of risk function. Such natural dynamics include changes in the probabilities or intensities of hazards due to climate change on the one hand and socioeconomic developments on the other (*Elmer et al., 2012; Cammerer et al., 2012; Cammerer and Thieken, 2013*). The latter include land use changes, demographic changes and changes in asset values at risk, as well as changes in the vulnerability of such elements at risk and the adaptive capacity of communities (*cf. Hufschmidt et al., 2005; Bouwer et al., 2011; Przyluski and Hallegatte, 2011*). These dynamics are only rarely reflected in current cost assessment practice. In other words, it is often assumed that the current risk situations will not change and annual average damages figures are simply extrapolated into the future. Just a few studies to date have attempted to integrate both climate change scenarios and socio-economic change scenarios.

6. HEC-FIA Approaches

In this part, the approach of HEC-FIA software for assessing the direct losses in the case of flood hazard will be investigated. By means of these explanations, sate of art in damage modeling could be linked to the next chapter which is related to the behind logics of damage calculation in HEC-FIA model.

♣ Perspective Damage Calculation in HEC-FIA: With the HEC-FIA model the calculation of direct damage is possible. These consequences are related to:

✓ Structural damages : Direct and tangible

✓ Content Damages: Direct and tangible

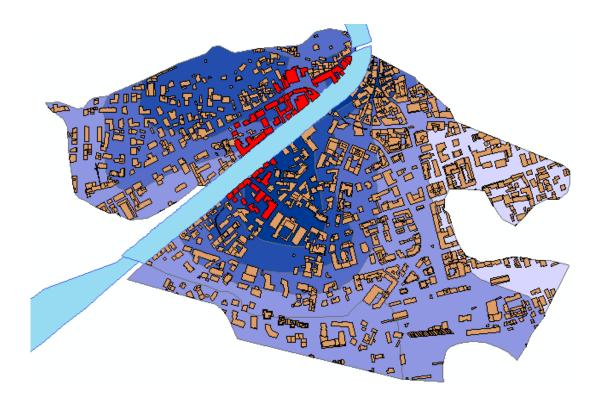
✓ Agriculture losses: Direct and tangible

✓ Life Losses: Direct and Intangible

- General Approaches for Economic Damage Assessment: It is an exante damage assessment with the help of user defined stage-damage curves or fragility curves which represent the relative percentage loss with respect to a pre-defined maximum damage value. Also, this value can be expressed as either replacement cost or depreciated/repair cost (User Choice).
- ♣ Spatial Scale: As it is shown in the next chapter, depend on the cost and the time of the project, by defining point shape file (*left picture*) or parcel shape file (*right picture*), spatial scale would be in Micro or Meso Scale. So, the users can query the damages at the individual structure level or at the large regional levels.



- ♣ Input Data: Three different segments is considered in HEC-FIA damage calculation:
 - ✓ Structural Damages: Maximum inundation depth is considered as the input of structural damages. HEC-FIA with the help of maximum depth, structure attributes (value, occupancy type, damage category and foundation height) and the related user-defined damage curves, calculate the percentage of direct-physical losses of structure and contents. It is worth noting that different economic sectors and type of buildings are definable by occupancy type and damage category and for each sector and its assets, user can define a separate damage curve.



- ✓ Agriculture Loss: By defining the information related to geospatial location of crop, crop value, yield per acre and the harvest cost (variable in any day of the year), agriculture losses is calculated with the help of hydraulic data such as depth, duration and arrival time of the flood.
- ✓ **Life Loss:** Hydraulics data such as arrival time of the flood, maximum depth of water are important in life loss assessment. Also, evacuation information like warning system, mobilization trend, demography of population and hazard boundary are required as well.

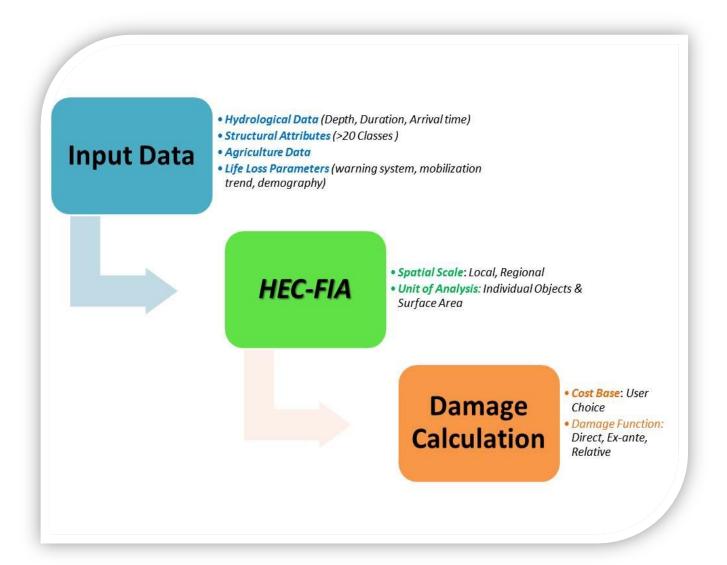


Figure 10.Summary for HEC-FIA Damage
Methodology

Chapter Three: Behind Logics of the HEC-FIA

1. Introduction

HEC-FIA (Hydrologic Engineering Center's Next Generation Flood Impact Analysis) is a stand-alone, GIS-enabled model for estimating flood impacts due to flooding used by United State Army Corps of Engineering. FIA includes a number of reports that detail these impacts. The impacts can be sorted by impact area, state, corps district, county, community, sub basin, township or flood control district. FIA is designed to facilitate:

- Assessment of disaster impact after a flood.
- ♣ Analysis of flood impact in real time to assist with decision making and response activities.
- Development of annual reports of crops' project benefit.
- Development of consequence estimates to support risk assessments for dam safety.

The software tool can generate required economic and population data for a study area from readily available data sets and use the data to compute:

- Urban structure damage
- Agriculture flood damage
- Area inundated
- Number of structures inundated
- Population at risk
- Loss of life
- Crops' project benefits

All damage assessments in HEC-FIA are computed on a structure-by-structure basis using inundated area depth and arrival grids, or hydrograph data. The life loss compute contained in HEC-FIA includes consideration of effectiveness of warning system, community response to alert and evacuation of large population.

HEC-FIA is also capable of analyzing economic and life safety benefits from various non-structural flood damage reduction measure, including installation of flood warning system, public education campaigns and flood-proofing or raising of individual structures. These estimation can be computed with uncertainty for single catastrophic failure (due to complexity of hazards in reality), so that decision makers can be aware of which parameters contribute that most uncertainty to the life loss estimations. (Lehman and Needham, 2013)

2. Economic Consequence Estimation with HEC-FIA

HEC-FIA was designed to estimate consequences from a single flood event for the purpose of determining how much damage was prevented by projects in the watershed for a specific event. More detailed economic analysis is able to be done in a single event calculation than in an annual maximum frequency based damage calculation because there is more information associated with the timing, duration and preparation for the specific event. For instance, longer duration have greater impact on agriculture damages and shorter duration floods have less impact on crops, but both damage estimates are highly dependent on when the flood happens in the season, so if identically sized events actually happened in different seasons the flood damage to crops could be significantly different.

In addition, to improve upon traditional USACE damage calculation where only stage is used in the calculation, HEC-FIA has attempted to take more damage driving parameters into account for the calculation of consequences. (Lehman and Needham, 2013)

2.1. Agriculture Data

One of the largest problems facing regional economists in the district offices when they are trying to compute any type of impact is a lack of recent and usable data. Agriculture damage calculation is very difficult to analyze without information on where the crops are located within the floodplain, how much value has been put into the crops and the duration flooding.

To solve the problem of data availability, HEC-FIA is designed with three different possible methodologies for importing data. Each one of them can be used based on the user preferences:

- User can create a polygon that represents the area planted in different crop type.
- User can use information from FEMA HAZUS database that stores the percentage of cropland planted with different corps at the census tract level.

After geospatial location of crop information is determined, the user will have to define the crop value, yield per acre and the harvest cost for the crops. This information will be used to help determine the value in the field for any day of the year and specifically for the time at which the flooding occurs.

The formula for calculating seasonal damages is broken into two pieces as bellow:

$$S(t,c) = \left(a.\left(V(c) - H(c)\right)\right).B(t)$$

Where:

S = seasonally based value as a function of date and crop type

t= date

a= the area of the grid cell in acres

c= crop type

V= the value as a function of crop type

H= the harvest cost as a function of crop type

B= the percentage of the total crop value that is available to be flooded due to the crop budget

$$D(t,d) = S(t,c).L(d,c)$$

Where:

D= damage to the crop as a function of date and duration

d= duration of flooding

L= the loss for the crop as a function of duration and crop type

(Lehman and Needham, 2013)

2.2. Structure and Content Data

To compute the economic damages associated with structure and their contents HEC-FIA looks at structure attributes like value, occupancy type, damage category and foundation height. In order for HEC-FIA to know the information necessary to compute structure and content damages, the user is required to input a detailed structure inventory defining various attributes about each individual structure. The process of collecting the required inputs can be very time consuming and potentially prohibitive due to costs depending on the scope of the project. To alleviate some of that cost HEC-FIA has created a methodology to use FEMA HAZUS database to create structure inventories with required attributes quickly and in an automated fashion.

There are essentially four methods to generate a structure inventory in HEC-FIA:

Using the HAZUS database :

When HEC-FIA generate the inventory from the HAZUS database, it imports the necessary attributes for a damage assessment using HEC-FIA and splits the structures into forty different structures occupancy types(to distinguish heavy industrial from light industrial etc.) and four different damage categories (to distinguish residential from industrial) depending on data collected and defined for each census block.

(*Left Figure*)

Overall, a few of the shortcomings of the structure inventories generated by HEC-FIA using the HAZUS database are the geographic

placement of the structures and the value of the structures that should be checked by the user.

Using a parcel database:

The quickest way to get reasonably close to the detail achieved by a point shape file is to use a parcel shape file database to define the attributes and the centroid of each parcel to represent the point for each structure.

The necessary attributes that need to be defined to construct such an inventory for economic damages are foundation heights, structure types, depreciated replacement value, content value (or a ration of content to structure value), structure category and unique structure name. In this method the user will make life loss calculations with the help of some available tools and the census information stored in the HAZUS database. (*Right Figure*)

Using a point shape file:

The most detailed inventory would be a surveyed point shape file with all the attributes of the structure inventory assigned to each point and direct stage-dollar damage functions defined for each unique structure.

Through manual entry by the user



As it is shown in the above figure, the inventory generated by HAZUS is spread out much more compare to the alternative generated by parcel method, while the parcel data inventory shows the structures clustered closer together in populated areas. But it is worth noting that both databases contain a similar number of structures across the entire study. (*Lehman and Needham*, 2013)

2.3. Inundation Data

Once the structure data is imported into the HEC-FIA project, the inundation data will be imported into HEC-FIA as depth grids. Although all you need to compute structure damages in HEC-FIA is a depth grid, adding a grid of the maximum product of depth and velocity achieved over a simulation will allow a more detailed structure damage calculation.

Arrival time grids and duration grids or hydrograph data at cross sections from the hydraulic model are required for agriculture damage estimates and also, arrival times and depth grids are required for life loss estimation which will be explained in the next parts. (Lehman and Needham, 2013)

Overall and with regard to the mentioned issues, for structure and content damages HEC-FIA will look at each structure and identify the depth at the structure from the gridded data and associate the depth with the depth damage curve defined by the structure occupancy type which will result in amount of damage for each structure impacted. If the user chooses they can individually assign structure damage curves to each structure taking into account the unique damages associated with each structure. Similar process will be happening coincidentally with the content depth damage curves. The resulting damages will be stored at each individual structure and at predefined geographic areas, so that users can query the damages at the individual structure level or at the large regional levels. All information generated can be exported through a point shape file representing each structure damaged by the event so that GIS tools can be used to display and analyze results in any way the user wishes. HEC-FIA can also estimate the value of the structure over time as it is being rebuilt, so that if multiple event hydrograph are supplied where structures are repeatedly flooded, the damage calculation will not damage the structure at full value during the subsequent events unless it has had sufficient time to rebuild to full value. (Lehman and Needham, 2013)

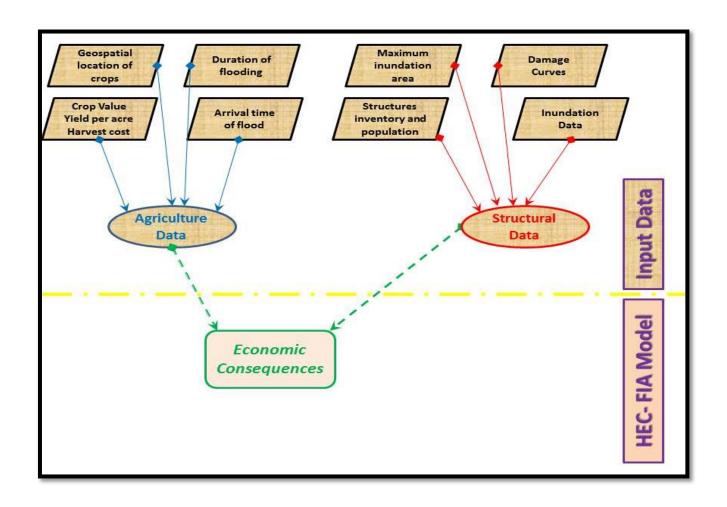


Figure 11.Logic Chain of Economic Consequences

3. Life Loss Estimation with HEC-FIA

The **Simplified LIFESim** methodology is applied with the HEC-FIA software program for estimating life loss. In below first, we will explain the **LIFESim** methodology and after that the main differences between the **Simplified LIFESim** methodology applied within HEC-FIA and the **LIFESim** will be discussed.

3.1. LIFESim Methodology

LIFESim is a modular, spatially-distributed, dynamic simulation system for estimating potential life loss from natural and dam and levee failure flood. Development of LIFESim has been sponsored by the **USACE** and the **A**ustralian **N**ational **C**ommittee **o**n **L**arge **D**ams (**ANCOLD**).

LIFESim has been formulated based on the important processes that can affect life loss, while depending on only readily-available data sources and requiring only a reasonable level of effort to implement. It comprises the following internal modules: (Aboelata and Bowles, 2006)

- **Loss of shelter**, including prediction of building performance
- Warning and Evacuation
- Loss of Life

3.1.1. Loss of Shelter Module

The Loss of Shelter Module simulates the exposure of people in buildings during each flood event as a result of structural damage, building submergence and toppling of people in partially damaged buildings. Loss of Shelter categories are assigned to each level in several types of buildings throughout historical fatality-rate and the probability distributions were estimated by McClelland and Bowles [2002]. Three flood zones which are physically defined by interplay between available shelter and local flood depths and velocities, summarized as bellow (Aboelata and Bowles, 2006)

- ♣ Chance Zones: In which flood victims are typically swept downstream or trapped underwater and survival depends largely on chance. The historical fatality in Chance Zones ranges from about 50 percent to 100 percent, with an average rate over 91 percent (shown by Prcz in the bellow figure). (Aboelata and Bowles, 2006)
- **↓ Compromised Zones**: In which the available shelters has been severely damaged by the flood, increasing the exposure of flood victims to violent floodwaters. The historical fatality rate in *Compromised Zones* ranges from zero to 50 percent, with an average rate near 12 percent (shown by Prcoz in the bellow figure). (Lehman and Needham, 2013)
- ♣ Safe Zones: Which are typically dry, exposed to relatively quiescent floodwater or exposed to shallow flooding unlikely to sweep people off their feet. Fatality rate in Safe Zones is virtually zero and averages 0.02 percent (shown by Prsz in the bellow figure). (Lehman and Needham, 2013)

COMBINED DATA

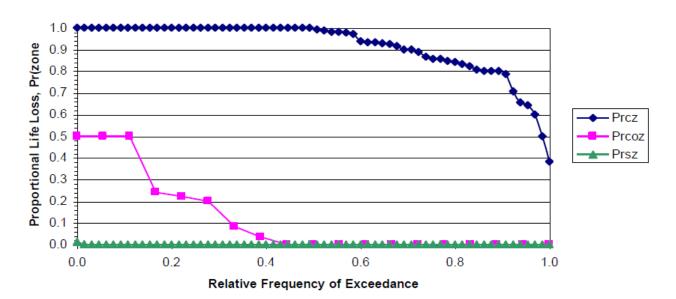


Figure 12.Loss of Life Modules

3.1.2. Warning and Evacuation Module

A sensitivity study demonstrated the critical role that warning initiation time plays in the opportunity for evacuation and in determining fatality rate.

■ Warning Issuance Time: The Warning Issuance Time is defined as the time at which an official evacuation order is released from the responsible emergency management agency to the population at risk. Life Loss estimation are highly sensitive to warning issuance time and other relationships that affect the effectiveness of warning and evacuation processes for the population at risk. Following graph is an example for case of dame failure: (Lehman and Needham, 2013)

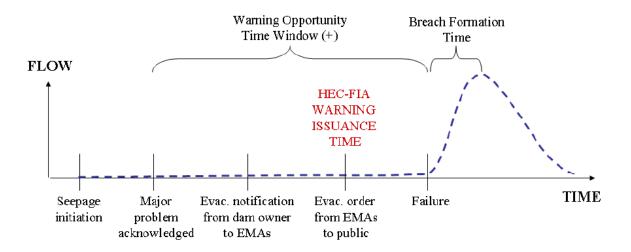


Figure 13.Warning and Evacuation Process

Warning System Time and Information: The amount of time it takes from when the evacuation warning is issued by the responsible agency (warning issuance time) until the population at risk receives the warning dependent on the warning system or process that is used to provide that warning. Also, the daily activity budget of a population is used to evaluate the effectiveness of different warning system over time. The default warning dissemination process is provided to HEC-FIA in the form of warning diffusion curves that shows the relationship between time from warning issuance and the percentage of the population at risk that has received that warning. HEC-FIA has capabilities to define separate impact areas that can each be assigned different warning issuance times as well as different types of warning systems (Rogers and Sorensen, 1991) .As you can see in the image bellow the effectiveness of the Emergency Alert System is totally different in 2AM and 2PM due to change in the population's activity. (Lehman and Needham, 2013)

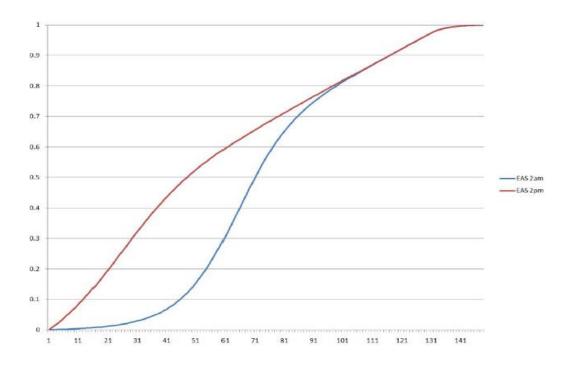


Figure 14.Emerancy Alert System

- ♣ Mobilization Time: After receiving the warning message, people who are willing and able to leave will prepare to leave. The rate of mobilization is represented in LIFESim using a mobilization curve, which is cumulative percentage of the warned people that start moving away from the area of potential flooding towards emergency shelters or other safe destinations (Aboelata and Bowles, 2006). At the time of arrival of the flood at a particular location some people may remain in buildings and evacuate vertically and they are included of people who have not received warning message or they have received the message but decided to not mobilize.
- **♣ Evacuation Time**: The time required to evacuate depends on many factors, including mobility, the location of shelters and the capacity of the evacuation route. The full LIFESim model includes derailed dynamic transportation simulation modeling capabilities to obtain estimates of the evacuation process throughout the inundation area (*Aboelata and Bowles, 2005; Aboelata et al, 2005*).

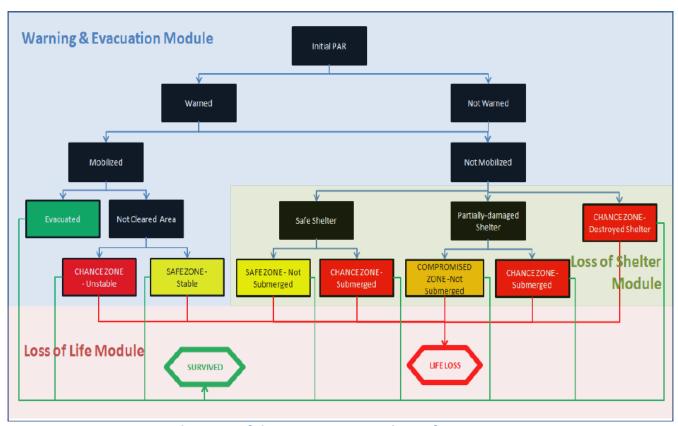


Figure 15. Schematic of the LIFESim Approach to Life Loss Estimation

3.1.3. Loss of Life Module:

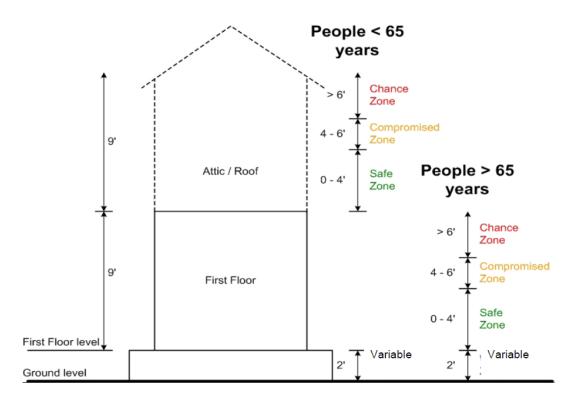
Based on the assigned flood zones categories (chance zone, compromised zone and safe zone), life loss estimates are made using life loss probability distributions developed by McClelland and Bowles [2002], updated Aboelata *et al.*,[2003].(See figure 12)

3.2. Lethality Zones

HEC-FIA assigns lethality zones based on the evacuation outcome for people starting in each structure and the height of the structure. The logic followed by HEC-FIA for assignment of evacuation outcome categories is described below:

- Cleared: The people that evacuate safely do not receive a flood lethality zone assignment.
- **Caught**: The people that get caught evacuating are assigned to the *Chance Zone*.
- Not Mobilized: The people that stay in structure are assigned to flood lethality zones based maximum depth of flooding over the entire flood event and the height of the structure. The assumption in Simplified LIFESim is that people evacuate to the level above the highest habitable level in the structure (e.g. the roof or an attic).

(Lehman and Needham, 2013)



Fatality rate in safe zone = 0.02%

Fatality rate in Compromised zone = 12%

Fatality rate in chance zone = 91%

3.3. Simplified LIFESim Differences (HEC-FIA)

The Simplified LIFESim methodology is applied within the HEC-FIA software program. The main differences between the Simplified LIFESim methodology applied within HEC-FIA and LIFESim methodology are as follows:

↓ Evacuation Simulation: HEC-FIA determines the shortest straight-line distance from a structure to the hazard boundary and applies a nominal evacuation speed along that line to estimate the amount of time required to evacuate. The effect of traffic jam potential must be accounted for implicitly by the choice of the nominal evacuation speed. (*Lehman and Needham, 2013*)

- ♣ Velocity: Simplified LIFESim does not account for the impact of water velocity on vehicle or human stability and therefore water velocity only influences the loss of life estimate based on the structure stability. In many cases, location that experience water velocities high enough to sweep a human or vehicle away will also experience depths large enough to inundate that human or vehicle, making the ultimate fatality rate the same. If flooding characteristics in the study area show many areas with high water velocities and relatively low depth, application of the full version of LIFESim should be considered to appropriately account for vehicle and human stability. (Lehman and Needham, 2013)
- ♣ Arrival Time: In the Simplified LIFESim, flood arrival time at a structure is computed by interpolating cross-section hydrograph output from a one-dimensional hydraulic model or from a grid that contains arrival time values.(Lehman and Needham, 2013)

3.4. Simplified LIFESim Inputs

- → **Digital Elevation Grid**: The digital elevation model is used to assign elevations to structures as well as the elevation of the safe location in the evacuation effectiveness computation.
- → Structure Inventory with population: Each structure must have a ground elevation, population for day and night and over and under the age of 65 and the number of stories for the structure at a minimum, its construction type and its foundation type is required for assigning fatality rates.
- ♣ Inundation Data for Each Flood Scenario: The Simplified LIFESim methodology requires an estimate of the time of arrival of the flood wave for each structure. The arrival time represents the end of the opportunity to evacuate a structure and by default is defined in HEC-FIA when the depth initially becomes greater than 2 feet and it is assumed that people will choose to evacuate vertically in a structure instead of trying to move horizontally to a safer location. (Lehman and Needham, 2013)

3.5. Overall Procedure of Simplified LIFESim Methodology

With regard to the mentioned issues related to LIFESim Methodology and the differences with the Simplified method and also based on the required inputs and assigned lethality zones, following steps will be considered by HEC-FIA for each selected Event-Exposure Scenario:

- Obtain the flood arrival time for each structure.
- ♣ Calculate the available time for each structure by finding the differences between their respective flood wave arrival times (from step 1) and the public warning issuance time.
- ♣ Combine the user defined warning and mobilization curves into one relationship that represents the number of people who have both received a warning and mobilized.
- Compute the percentage of people in each Evacuation Outcome Category.
- For each structure and based on the previous steps, assign a **lethality zone** to the people in each **evacuation outcome category** (as described before in section 3.2 and shown in the bellow figure).
- ← Calculate the life-loss estimate for each structure and not mobilized resident by multiplying the initial population of each structure by its respective overall fatality rate (as described before in section 3.2 and shown in the bellow figure).
- ← Calculate the total life-loss estimate by summing the life-loss estimates for all structure (from step 5 and 6)`

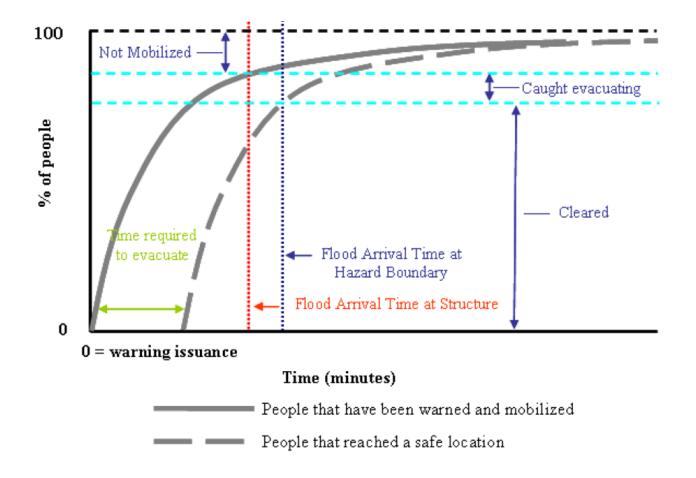


Figure 16.Overall Procedure of Simplified LIFESim Methodology

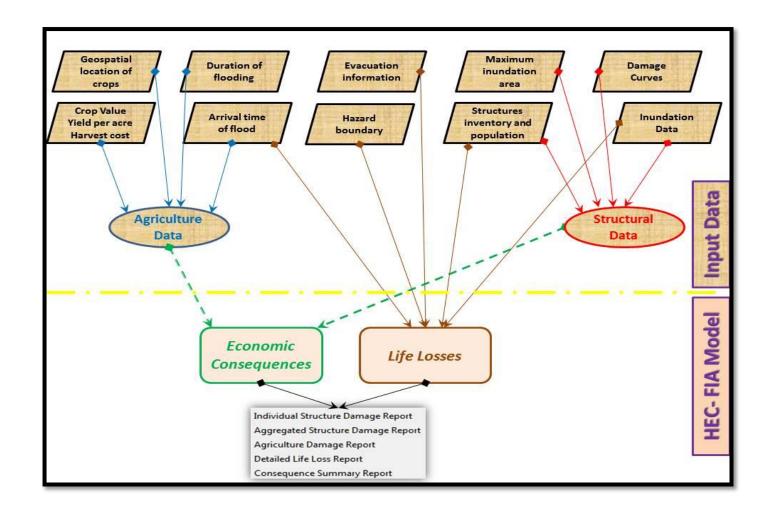


Figure 17. Overall Logic Chain of HEC-FIA Model

4. Structural and Non-Structural Measures

One of the key features in HEC-FIA is the ability to quickly analyze structural and non-structural measure for both economic and life loss. The user is given the opportunity to raise houses, move houses and provide ring levees around houses to alter the economic damages. Doing these types of measures will also have an effect on the life loss estimates by changing the fatality rates that will be assigned to structures when they are raised or by removing the house from areas of significant depth through relocation. In addition to these measures, HEC-FIA can quickly facilitate the analysis of improving warning systems to improve the speed of warning diffusion or decreasing the amount of time required for the warning to be issued by changing the procedures outlined in the Emergency Action Plan for a particular project. This non-structural measures will also possibly reduce the economic losses by allowing sufficient lead time for the population to remove vehicles and remove structure contents to higher elevations inside their structures. HEC-FIA can also allow the users to create locations for shelter in place protection from flood waves and by shortening evacuation routes make it possible for people to quickly get to safety through vertical evacuation in structures designed to withstand the flood wave. Overall, the analysis of these measures allows the user to find ways to reduce risk of economic and life loss within their floodplain. (Lehman and Needham, 2013)

-Digital Elevation Grid -Economic Impact Consequens -Agriculture Data Pre--Structure & -Life Loss **Processing Inventory Data Estimation** With -Other Social -Inundation & With **Effects Associate Impacted Area** ARC-GIS with Hypothetical **HEC-FIA** -Region With the Flood Scenario unique Warning Systems

Figure 18.Data Preparation for Consequence Estimation in HEC-FIA

Chapter Four: *Conclusion and Future Works*

HEC-FIA model has the possibility of calculating only direct damages in a single catastrophic event. Regarding the discussed issues, HEC-FIA is following the Simplified LIFESim method for life loss estimation which is well prepared in regard of assessing loss of shelter and loss of life estimation. Another strength point of HEC-FIA in this regard is related to evaluation of the effectiveness of warning system, community response to alert and evacuation of large population. Also, this approach has opportunity for calibration with extreme events in regard of improving the effectiveness of emergency preparedness plans and simulation exercises. Although using the simplified version of LIFESim in HEC-FIA needs less effort compare to full version of LIFESim and simulation will be easier for the users, being away of consideration of all details will leads to raising the level of the approximation. Some examples of the approximation in simplified version could be named as: not considering the velocity of floods, selecting the shortest straight-line distance from a structure to the hazard boundary in evacuation procedure instead of considering the real urban road plan and doing some interpolation for hydraulics data. Furthermore, in HEC-FIA for life loss estimation we need to define the hydraulics data with the method of grid-depth. In this method calculation of the economic losses for the structures with the basement which are situated out of the water depth grids and probably have a negative depth is impossible.

Structural damage calculation will be performed based on the damage curves which will be definable manually by the user and it will be flexible in regard of considering different classes and considering the replacement or depreciated cost. Another strength point of HEC-FIA is related to possibility of damage query at the individual or regional scale (user choice) and also HEC-FIA can consider the time of rebuild for the structures which are flooded repeatedly. In addition, the only hydraulics input which will be considered in structural damage assessment will be the stage of the water. Although depth is one of the most important inputs in flood damage assessment, ignoring some factors such as duration, velocity, debris and contamination could lead to underestimation of the losses.

In HEC-FIA, agriculture loss estimation is improved compare to traditional approaches of USACE and it could be done by more accuracy in regard of input data. But on the other hand, preparing information by this level of detailing for regions which are located out of USA could be a little complicated. In addition, we can use HEC-FIA in regard of development of annual reports of crops' project benefit as well. HEC-FIA is well-prepared and user friendly in regard of considering different scenarios for mitigation measures such as installation of different flood warning systems, public education campaigns and flood-proofing or raising of individual structures. Results calculated in each scenario are easily comparable with others.

Thanks to the possibility of linking HEC-FIA with GIS software and its' good visualization, damage assessment could be developed in future projects for designing a smart Geospatial Information Platform. The smart Geospatial platform will perform real-time collection, management, analysis, distribution, and visualization of information for enhanced situation awareness. The smart platform will provide immediate relationships of a location to a disaster. This real-time stream of critical information will populate optimization/simulation engine whose goal is to increase the cognitive abilities of decision makers when faced with an urban disaster of large magnitude and uncertainty. In this way and with the help of HEC-FIA abilities we can resolve some crucial issues in regard of damage assessment procedure such as uncertainty of information and multiple sources of data in disaster duration and decision makers can make key decisions in regard of damage assessment and resource allocation with less uncertainty while these large amounts of timely information is updating dynamically.

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