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**Project title: “Loss of life, evacuation and emergency management – application of Dutch models to US case studies”**

**Second Interim report**

**Date:** Dec 18, 2012      Approved for public release; Distribution unlimited

**Drafted by:** Sebastiaan N. Jonkman, Technische Universiteit Delft, the Netherlands

**Abstract:**

The objective of this project is to investigate the application of Dutch models for Loss of life and evacuation analysis to US case studies. Within this second phase we have made analyses of life loss for the Natomas Basin (CA) as part of the comparison effort. We have also had a workshop with USACE experts from Nov 26 – 29 (2012) in Davis (CA) to discuss the comparison effort and the activities in the case studies for New Orleans and the Herbert Hoover Dike that will be undertaken in the next steps.

**Appendices to this first interim report:**

1. Outline of the Technical report
2. First drafts of sections 1 and 2 of the report
3. Loss of life analysis for the Natomas Basin, preliminary results

**Nest steps / next phase (Dec 18 – Jan 15, 2013):**

- Completion and reporting of Natomas Basin case study (draft before Jan 1)
- Flood simulations and loss of life analysis for New Orleans
- Loss of life analysis for the Herbert Hoover Dike
- Reporting (third interim and final report)

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## Appendix 1: Report outline

**Title: Loss of life, evacuation and emergency management – comparison effort and application of Dutch models to US case studies**

**Authors:** Jonkman, Maaskant, Lehman, Zethof, Kolen

### Section 1: Introduction (Jonkman)

- 1.1 Background
- 1.2 Objectives
- 1.3 Report overview

### Section 2: Methods for loss of life and evacuation analysis

- 2.1 General introduction (Jonkman)
- 2.2 Methods for loss of life estimation
  - o 2.2.1 Interpolated 1953 mortality functions (Jonkman)
  - o 2.2.2 New Orleans / Katrina mortality functions (Jonkman)
  - o 2.2.3 HEC FIA approach (USACE)
  - o 2.2.4. Loss of life methods comparison (USACE)
- 2.3 Dutch Evacuation and Evacuaid approach (Kolen)
  - o 2.3.1 Evacuation approach implemented in HEC FIA (USACE)
  - o 2.3.2 Evacuation approach implemented in Lifesim (USACE)
  - o 2.3.3. Evacuation analysis applied in the Netherlands (deterministic) (Kolen)
  - o 2.3.4. Evacuaid, probabilistic evacuation approach (Kolen)
  - o 2.3.5 Evacuation methods comparison (Kolen)

### Section 3: Natomas Basin case study (Zethof)

- 3.1 General area description / overview
- 3.2 Data and assumptions – describe scenarios, assumptions etc.
  - o Flood scenarios
  - o Flood maps
  - o Population data
  - o Other assumptions
- 3.3 Loss of life Comparison effort, results:
  - o Interpolated 1953 method
  - o New Orleans method
  - o HEC FIA (to be provided by USACE)
  - o Lifesim (to be provided by USACE)
  - o Discussion of differences and similarities
- 3.4 Evacuation analysis comparison efforts (Kolen) – NB in this section we compare the deterministic evacuation curve(s) results and approaches
  - o Scenario 48 hours in advance
  - o Scenario 6 hours in advance

- 3.5 Exploratory / additional analyses:
  - 3.5.1. Conceptual ideas for risk analysis for Natomas Basin
    - General approach
    - Failure probability estimates based on fragility curves (Maaskant / Jonkman)
    - Overview of loss of life estimates for various scenarios
    - Example of Risk calculation, individual, societal risk
    - Discussion (Jonkman)
  - 3.5.2. Application of Evacuaaid to the Natomas Basin (Kolen)

#### Section 4: Herbert Hoover Dike case study

- 4.1 General area description / overview
- 4.2 Data and assumptions – describe scenarios, assumptions etc.
  - Flood scenarios (20 ft and 30 ft lake levels), breaches near Clewiston and Bella Glade.
  - Flood maps
  - Population data
  - Other assumptions
- 4.3 Loss of life Comparison effort, results:
  - Interpolated 1953 method
  - New Orleans method
  - HEC FIA (to be provided by USACE)
  - Lifesim (to be provided by USACE)
  - Discussion of differences and similarities
- 4.4 Bonus (if time permits): Evacuation analysis
  - Deterministic evacuation analysis
  - Evacuaaid

#### Section 5: New Orleans and hurricane Katrina case study

- 5.1 General background and purpose (Jonkman)
- 5.2 Overview and documentation of datasets (Maaskant)
  - Flood maps
  - Loss of life dataset
  - Building damage dataset
- 5.3 Loss of life Model comparison for Katrina (Maaskant)
  - Katrina mortality curves
  - Interpolated 1953 curves
  - Lifesim / Hec FIA results (USACE)
  - Model Comparison with life loss dataset
- 5.4 Post-Katrina scenario analysis
  - Background and objective (Jonkman)
  - System overview and scenarios and assumptions (Zethof)
  - Results, loss of life estimate (Zethof)
  - Discussion and further application in risk assessment (Maaskant / Jonkman)

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## Section 6: Findings and recommendations

- 6.1 Conclusions related to comparison effort (Maaskant)
- 6.2 Synthesis and suggestions for development of best practices for loss of life and evacuation analysis
- 6.3 Recommendations

## References

## Appendices:

- Model assumptions, inputs, outputs
- Methodological backgrounds (e.g. details about Evacuaid and loss of life functions)

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**Appendix 2: Drafts of sections 1 and 2 of the report**

# **1 Introduction**

## **1.1 Background**

Both in the USA and in the Netherlands extensive studies on approaches for identifying flood risks (including levee failure probabilities and consequences) are ongoing. The outcomes of these methods will provide a better insight in the actual level of risk and contribute to a better and more cost and time efficient prioritization of risk reduction actions. In recent years there has been a lot of information exchanged between experts from the Netherlands and the USA on these topics, e.g. within the Memorandum of Understanding between USACE and Rijkswaterstaat, during a seminar (May 13, 2011) that brought together about 50 experts from the Netherlands and the USA on levee safety<sup>1</sup>.

One topic that has received a lot attention in recent years is the (estimation of) loss of life due flooding and the associated risks. Historical events, such as the 1953 flooding in the Netherlands and the flooding of New Orleans due to hurricane Katrina, have demonstrated that life loss can be significant. Both in the US methods have been developed to estimate these consequences, and in both countries life loss will be considered in (future) policies and decision-making. It is therefore important that credible and reliable methods are available to analyse this type of consequences. Various methods have been developed in the Netherlands, US and other countries for various fields of application such as levee failure, dam breaching and tsunamis. Although these methods provide first insights in the range of loss of life that could be expected, there are still a lot of questions related to the empirical foundation of these methods and their application for policy decisions.

A related topic concerns evacuation and emergency management (EEM). The risks to life are directly influenced by the effectiveness of EEM. One challenge is to improve estimates of and insights in evacuation effectiveness, based on empirical data and the joint research efforts of social scientists and more engineering related research.

## **1.2 Objectives and Scope**

In recent years experts from the Netherlands and the US have exchanged knowledge and information on methods for loss of life due to levee and dam breaching. However, a case study in which various approaches for analyzing loss of life and EEM are rigorously compared has not yet been executed.

Therefore, the first and main objective of this study is to compare methods for analysis of loss of life and evacuation for a number of case studies in the US. This is referred to as the comparison effort in the remainder of this report.

A second, additional objective, is to explore how approaches for analysis of risk to life and EEM that have been recently developed in the Netherlands, can be applied in the United States.

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<sup>1</sup>

[http://ccrm.berkeley.edu/resin/pdfs\\_and\\_other\\_docs/RESIN\\_May13\\_levee\\_Seminar\\_proceedings.pdf](http://ccrm.berkeley.edu/resin/pdfs_and_other_docs/RESIN_May13_levee_Seminar_proceedings.pdf)

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Overall, it is the aim of the research efforts in this project to contribute to the improvement of methods for loss of life estimation, risk assessment and emergency management, both in the Netherlands and the US.

The scope of this report is limited to methods developed in the Netherlands and methods developed by USACE (HEC FIA and Lifesim). However, the approach in the comparison effort has been chosen in such a way that other methods can be added to the comparison effort relatively easily in the future.

The analyses and cases in this report mainly focus on larger-scale floods due to levee failure. Other types of floods, such as dam breaching and flash floods, have not been directly considered as part of the case studies, but can be part of future investigation.

### **1.3 Report outline**

The report is structured as follows. Section 2 gives a general overview and comparison of methods for loss of life estimation and evacuation analysis that have been developed in the Netherlands and the United States.

A number of case studies have been selected to be included in the the comparison effort. These include the Natomas Basin (section 3) and the Herbert Hoover Dike (section 4). In these sections first the results of loss of life and evacuation models have been compared. In the final parts of these sections some additional and more exploratory analyses have been added to investigate the application of new concepts for risk analysis and evacuation decision-making support, e.g. by means of the Evacuaaid model.

As a third case study the case of New Orleans has been investigated (section 5). A number of datasets that provide more information on life loss, building damage and flooding during Katrina have been summarized, as a basis for the model comparison effort for the case of Katrina.

In the final section 6, a synthesis of main findings is provided and recommendations related to future research, applications and the development of best practices for loss of life estimation and risk analysis.

### **1.4 Acknowledements**

USACE

FC 2015

## 2 Methods for loss of life and evacuation analysis

### 2.1 General introduction

#### General

The loss of life due to flooding is one of the most important types of consequences. Several methods have been developed to estimate the number of lives lost due to flooding. These models can be used for different purposes, such as the support of policy and engineering design decisions that are related to (acceptable) flood risk and to provide information to planners and emergency managers to improve and optimize their strategies.

Examples of loss of life models are the empirical method developed for storm surge flooding in the Netherlands (Jonkman, 2007), the flood risks to people approach developed in the UK (Penning Rowsell et al., 2005), models developed for levee and dam breach flooding in the US (HEC FIA and Lifesim) and agent based models, such as BC Hydro's LSM, that give a detailed simulation of flooding and people movement and behaviour. More comprehensive overviews and discussions of the various methods are included in (Jonkman, 2007; Jonkman et al., 2008, di Mauro et al., 2012).

A general characterization of various models is shown in Figure 1 with respect to their level of detail and modelling principles. The level of detail (vertical axis) varies from the modelling of each individual's fate to an overall estimate for the whole event. On the horizontal axis the basic modelling principles are categorised. Mechanistic models are those that model the individual behaviour and the causes of death. Empirical models relate mortality in the exposed population to event characteristics.

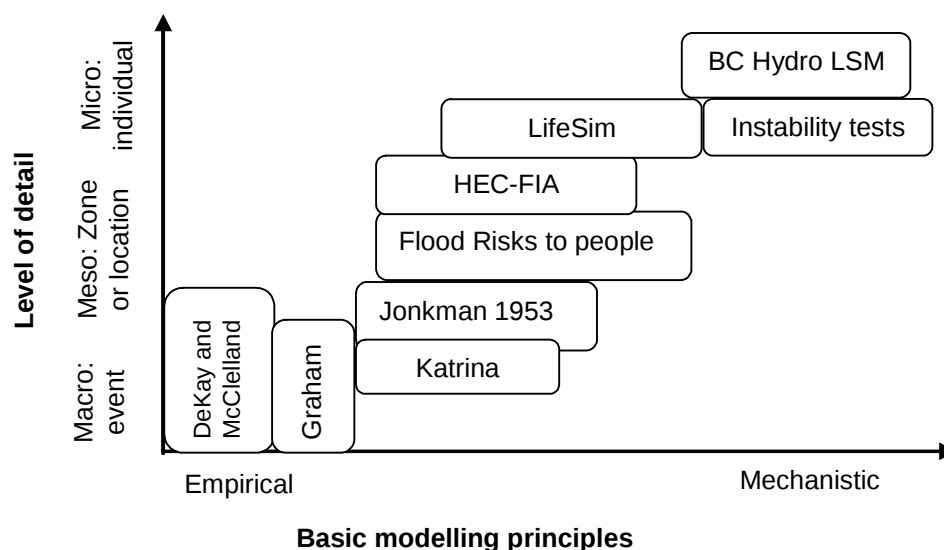


Figure 1: Comparison of loss of life models (based on Johnstone et al., 2005)

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## Loss of life estimation and evacuation analysis

Estimation of the loss of life requires insight in a number of variables and elements that can be clarified based on the formula below (Jonkman, 2007):

$$N = F_d(1 - F_E)N_{PAR} \quad (1)$$

Where:

$N$  – loss of life estimate;  $F_d$  – mortality fraction;  $F_E$  – evacuation fraction (also evacuation effectiveness),  $N_{PAR}$  – number of people at risk.

The mortality fraction ( $F_d$ ) expresses the ratio between the number of people killed and the number of people exposed in the floodzone, i.e. those present when the water arrives. Note that a different definition is used in the USBR's DSO-99-06 method (Graham, 1999). There, the fatality rate is defined as

$$\text{Fatality rate} = \text{Loss of life} / \text{People at Risk} \quad (2)$$

This implies that evacuation effectiveness does not directly influence the fatality rate.

The mortality is generally expressed as a function of flood characteristics, such as depth, flow velocity and rise rate, and outputs of hydrodynamic flood simulations are generally used to estimate these parameters. In some models mortality is also related to structural building performance in flood loads. Some models, e.g. the models used in the Netherlands, apply one mortality rate to all people in an affected region, irrespective of the state that they are in. Other models, e.g. Lifesim, make a distinction of the various states that people can be in, e.g. in a building or car, and assign different mortality fractions to these groups.

To come to an adequate estimate of loss of life the effectiveness of evacuation ( $F_E$ ) is a key parameter. For example changing the evacuation effectiveness from 0.5 (50%) to 0.9 will reduce the life loss by a factor of 5, and changing it from 0.5 to 0.98 by a factor of 25. In the Dutch practice evacuation is defined as movement to a safe location outside the floodzone before the flooding or breaching starts. In the American practice, also evacuation and movement after breaching is considered.

In addition to evacuation out of the area, shelter in a safe location within the area can be considered. The effectiveness of shelter can be included in separate term in equation 1 (the shelter fraction) or it can be indirectly reflected in the mortality fraction.

Finally, the number of people at risk ( $N_{PAR}$ ) in the floodzone has to be identified. An estimate can be based on population data, and the number of people present during certain times of the day and year.

## Remainder of this section

In this chapter a further explanation and comparison is included of methods for loss of life estimation (section 2.2) and evacuation analysis (section 2.3) that are used in the Netherlands and the United States.

## 2.2 Methods for loss of life estimation

In this section the methods for analysis of loss of life that are used in the Netherlands and United States are compared. The contents of this section mainly focus on the estimation of the mortality fraction.

### 2.2.1 Approaches based on the 1953 flood in the Netherlands

In the PhD thesis of Jonkman (2007) a method has been proposed for the estimation of loss of life due to floods. It is applicable to low-lying areas protected flood defences and specifically focuses on large-scale flooding due breaching of flood defences due to river and coastal flooding.

The mortality functions have been derived based on data from the 1953 storm surge disaster in the Netherlands (1853 fatalities), UK (315 fatalities). Additional data from storm surge flooding in Japan during Isewan Typhoon in 1959 (5100 fatalities) has been added to the analysis.

Based on the observations from these historical floods, three typical zones with different mortality patterns have been distinguished (see also figure 2):

- **Breach zone:** Due to the inflow through the breach in a flood defence high flow velocities generally occur behind the breach. This leads to collapse of buildings and instability of people standing in the flow.
- **Zones with rapidly rising waters:** Due to the rapid rising of the water people are not able to reach shelter on higher grounds or higher floors of buildings. This is particularly hazardous in combination with larger water depths.
- **Remaining zone:** In this zone the flood conditions are more slow-onset, offering better possibilities to find shelter. Fatalities may occur amongst those that did not find shelter, or due to adverse health conditions associated with extended exposure of those in shelters.

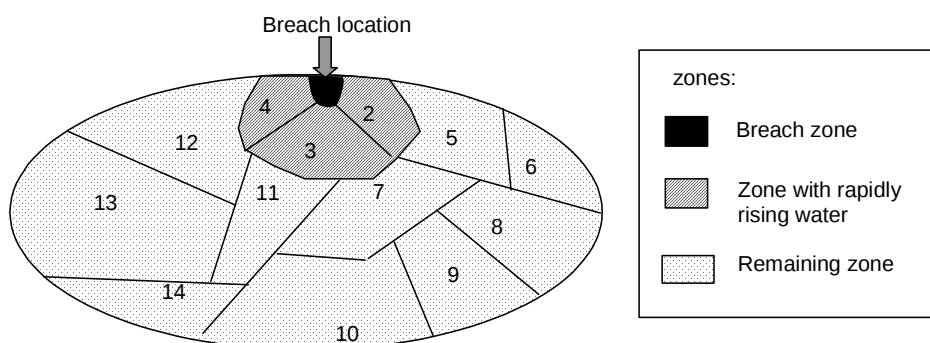


Figure 2: Zones in mortality estimation.

These zones are based on typical flow patterns after levee failure. For other types of floods, the situation and proportional area of the hazard zones might be different. For example for dam breaks in narrow canyons, the hazard zone associated with high flow velocities will be much larger.

For every zone a mortality criterion has been proposed. For the breach zone, no empirical data to calibrate the relationship between flow velocities and life loss was available. Therefore, a criterion has been proposed based on studies on building collapse. It is assumed that mortality equals  $Fd=1$  (i.e. 100%) if the combination of the combination of depth ( $d$  [m]) and velocity ( $v$  [m/s]) exceeds  $dv=7\text{m/s}^2$ .

For the other two zones mortality functions have been developed based on the historical data. Figures 3 and 4 show the mortality functions for the zone with rapidly rising water and the remaining zone. The two mortality functions explicitly include the effects of water depth. The numerical value of the rise determines which of the two functions has to be used and a threshold value of 0.5 m/hr was proposed. The function for the zone with rapidly rising water gives a good fit with the observed data and shows that mortality increases rapidly when the water depth increases. One uncertainty is the course of the function for larger water depths, as no direct empirical data is available to calibrate the trendline for these conditions. The bestfit trendline for the remaining zone is less adequate. For these observations the effects of warning and other factors, such as water temperature, preparedness and population vulnerability could be relevant

Figure 3: Mortality function for the zone with rapidly rising water (Jonkman, 2007)

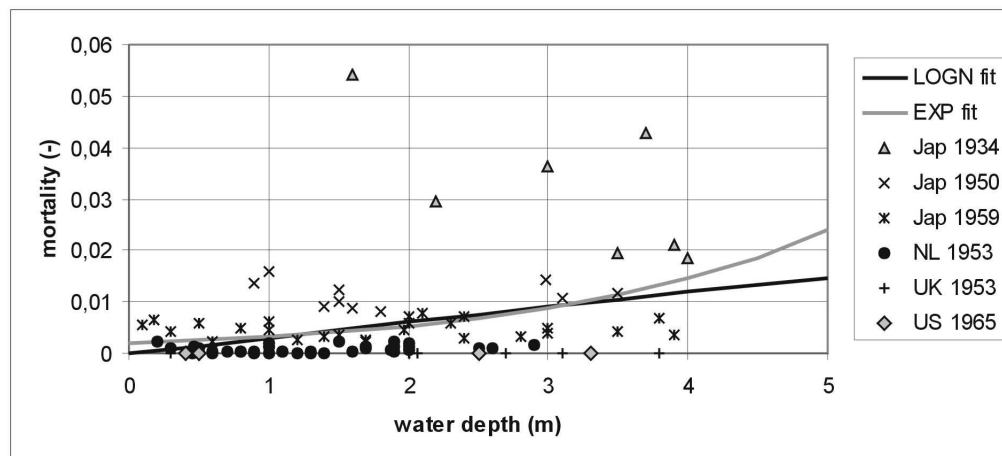


Figure 4: Mortality function for the remaining zone (Jonkman, 2007)

### Interpolated 1953 mortality functions

In a later revision of the method (Maaskant et al., 2009) the effect of the rise rate on mortality has been modified in the method based on the 1953 disaster. The rationale for the modification was that it appeared that there could be a very sudden jump in mortality if the threshold for the rise rate value of 0.5 m/hr was exceeded, especially in combination with larger water depths. It also appeared that the data of the 1953 storm surge did not give a very clear indication of what the critical threshold for rise rate would be. Based on the re-consideration of the rise rate information of 1953 and practical consideration it has been proposed to interpolate the mortality functions for rise rates between 0.5 m/hr and 4 m/hr. This effect is shown in the figure below and this area is labelled the transition zone. This function is currently implemented in the standard methods for consequence

assessment (HISSSM) in the Netherlands, and will therefore be used for further reference and comparison below.

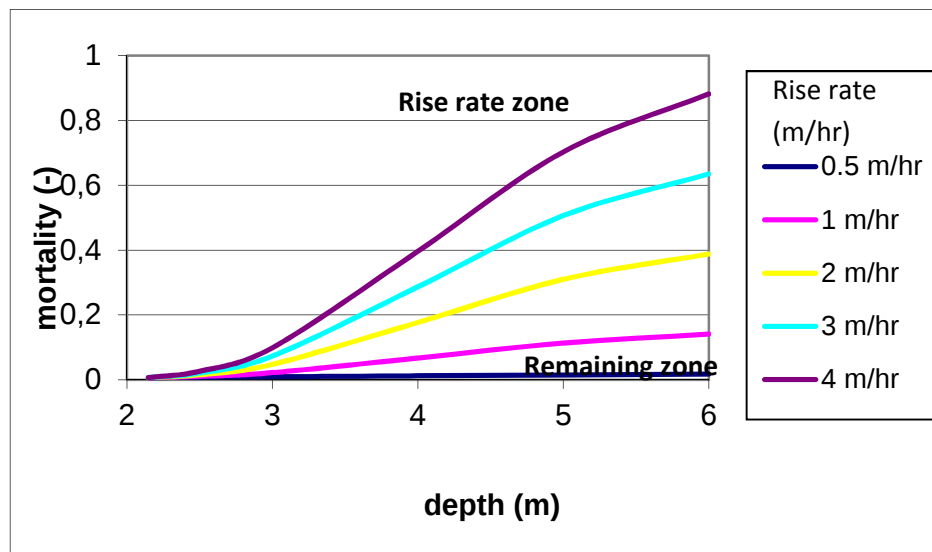


Figure 5: Interpolated mortality functions based on the 1953 disaster.

The complete set of equations for the method based on the 1953 flood disaster is included in appendix 2.1.

### 2.2.2 New Orleans / Katrina mortality functions

Hurricane Katrina struck New Orleans and the Gulf coast in the year 2005. This tragic disaster led to enormous destruction and more than 1100 fatalities, but it was also an important opportunity to learn.

A preliminary dataset that gives information on the recovery locations and individual characteristics for 771 fatalities has been analysed, see Jonkman et al. (2009), Maaskant (2007), Brunkard *et al* (2008) and Boyd (2011) for further background. Figure 3 gives an overview of the spatial distribution of recoveries in and near the flooded parts of New Orleans. A distinction is made between two categories of fatalities:

1. Recoveries from residential locations such as residences, nursing homes, street locations and public buildings. Fatalities in these facilities can often be directly related to the flood effects.
2. Recoveries from medical locations, shelters and morgues / funeral homes. These recovery locations indicate that these fatalities were not directly related to the impacts of floodwaters.

One third of the analysed fatalities occurred outside the flooded areas or in hospitals and shelters in the flooded area. These fatalities were due to the adverse public health situation that developed after the floods. Two thirds of the analysed fatalities were most likely associated with the direct physical impacts of the flood and mostly caused by drowning. The majority of victims were elderly: nearly 60% of fatalities were over 65 years.

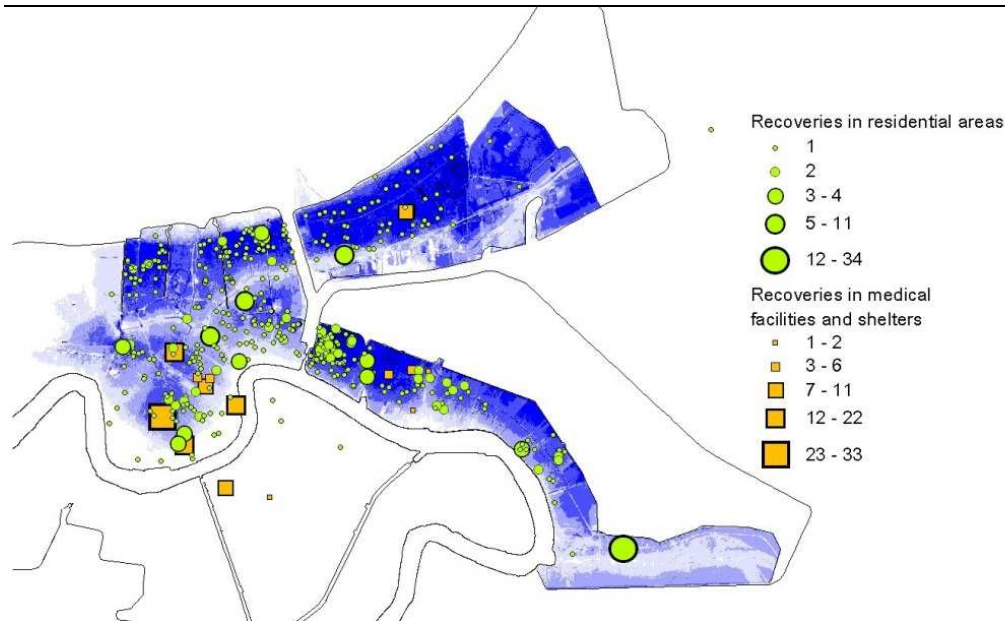


Figure 6: : Recovery locations and flooded area (Jonkman *et al.*, 2009)

The consequences of the flooding of New Orleans were relatively well-documented and these data provide additional insight in the relationship between flood characteristics and mortality. Based on the outputs of flood simulations the relationship between the mortality and various flood characteristics (depth, velocity, rise rate) has been investigated.

The analysis has been done at the neighbourhood level. In total 437,500 people lived in the flooded area in New Orleans. It is assumed that 10% of the population was exposed, since the evacuation rate was assumed to be 80% based on traffic counts and a shelter rate of 10% was assumed (see Jonkman *et al.*, 2009 for further details). Overall, it was found that mortality rates were relatively high in the areas with large water depths and areas directly behind breaches (Jonkman *et al.*, 2009). The overall mortality amongst the exposed population for this event was approximately 1%, which is similar to findings for historical flood events (see section 2).

The analysis showed that the rise rate did not have a significant effect on the mortality. There appeared to be a some relationship ( $R^2=0.42$ ) between the flood depth and mortality in the metro and St. Bernard bowls, see figure \*\*\*.

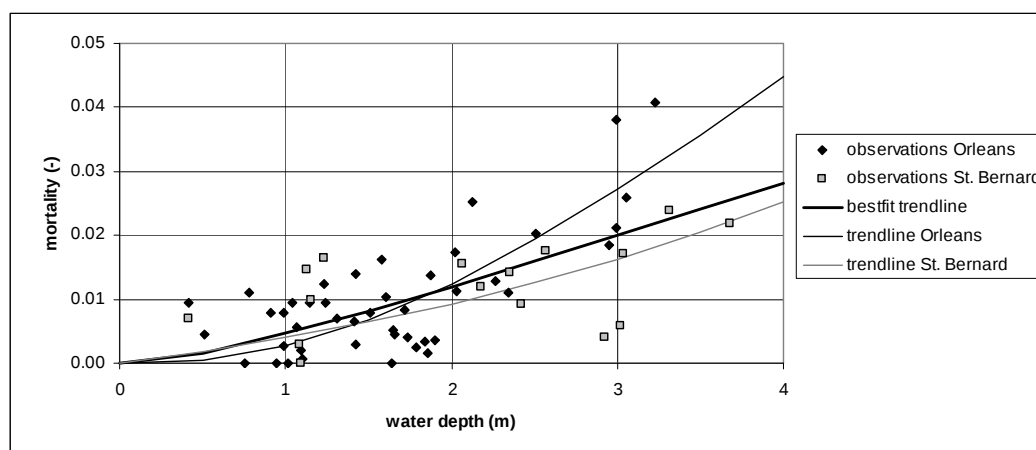


Figure 7: Relationship between water depth and mortality for the Orleans and St. Bernard bowls.

A large number of fatalities (73) occurred in the neighbourhood the Lower 9<sup>th</sup> Ward. This neighbourhood is located next to the two large breaches in the Industrial Canal levees. Various eyewitness accounts tell how the floodwater entered this neighbourhood through the breaches with great force and how it caused death and destruction in the areas near the breaches. Based on the flood simulations and building damage observations (Pistrika and Jonkman, 2009) it was found that higher mortality ( $F_d > 0.05$ ) occurred in areas where  $dv > 5 \text{ m}^2/\text{s}$ .

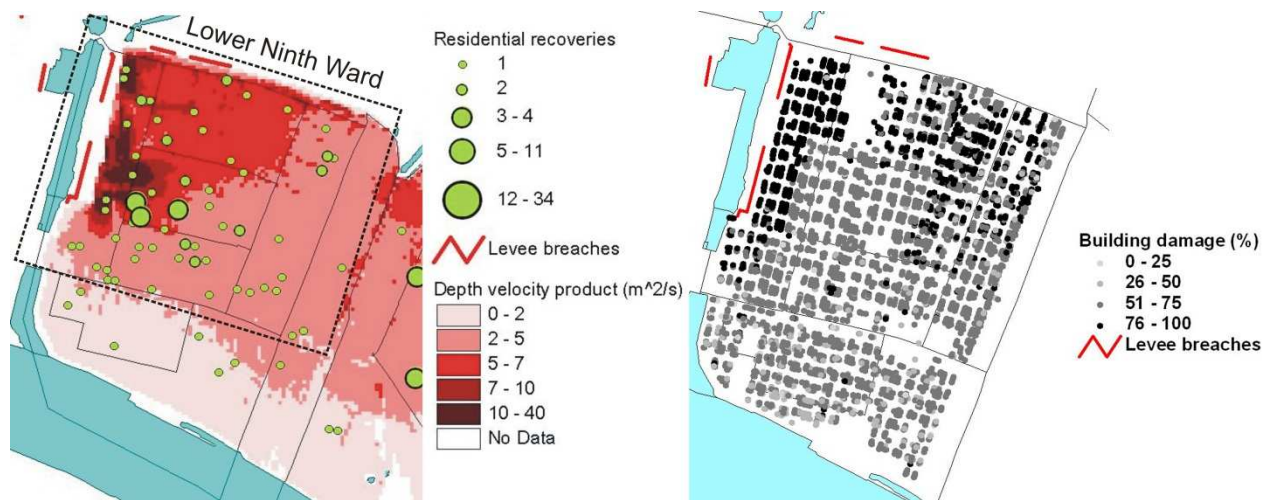


Figure 8: Spatial distribution of the recovered fatalities and the depth-velocity product for the Lower 9th Ward (left) and building damage levels (right - source:

<http://www.unifiedneworleansplan.com/home2/section/24>, accessed December 2006. Damage levels determined in post Katrina damage assessments conducted by the City of New Orleans and FEMA).

The approach for mortality estimation that follows from hurricane Katrina is summarized in figure \* below. The main difference with the method derived based on the 1953 disaster is that a) no effect of rise rate is found in the Katrina data; b) the mortality in the breach zone (5 – 10%) is much lower than assumed in the 1953 method (100%). When the 1953 method is applied to Katrina the predicted number of fatalities is within a factor 2 (over or under prediction). When both methods are applied to case studies in the Netherlands, the deviation in outcomes is relatively small and about 15% on average (Maaskant, 2007).

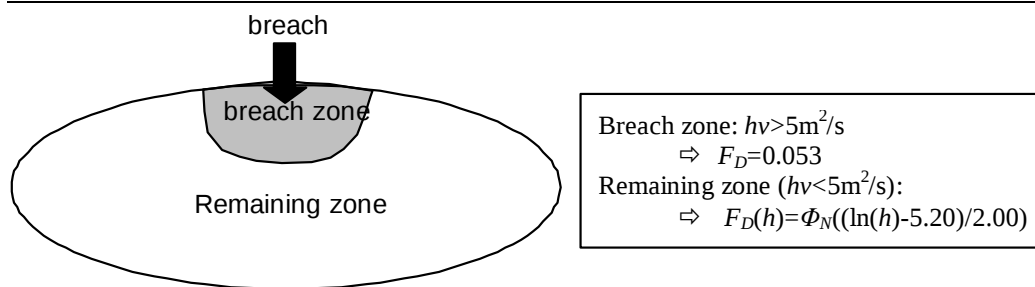


Figure 9: Mortality functions and zones derived based on data for the flooding of New Orleans.

### 2.2.3 HEC FIA approach

#### Methodology description

- Brief description of the model

HEC-FIA is a single event geospatially based model that calculates life loss and economic losses. The software can be used for rapid assessments of life loss at a rough level, but is very scalable to allow users to modify inputs and parameters to accurately describe the floodplain and the geospatial location of the population to get much better results for alternative analysis. HEC-FIA attempts to model the full progression of the flood wave with as little data as necessary, and the response of individuals to warnings and the flood wave. From the hydraulic inputs HEC-FIA looks at how well the structures and individuals survive based on their ending location and exposure to the hazard. HEC-FIA is a standalone program that can be run from a personal computer that is not connected to the internet. There is potential for significant GIS pre-processing for the structure inventory or other elements describing the floodplain, and hydraulic modeling

- Hydraulic inputs

HEC-FIA accepts information from multiple hydraulic model types, it can accept 2D model output in the form of grids (ascii, flt, or TMS), or it can bring in 1D hydraulic data via hydrographs at individual cross sections, or grids. For life loss the minimum required inputs are the arrival of water (2ft is default) and maximum depth achieved for each gridcell,. If more detailed analysis is desired, the maximum of depth times velocity across the modeled time for each gridcell can be provided to determine the impacts of velocity on life loss.

- Population/structure inventory

HEC-FIA uses a geospatially based methodology to describe the built inventory. Structures are defined as points on a map for x and y location, and have their z value or elevation determined by a digital elevation map (DEM). Structures can be added into HEC-FIA through many different methodologies, by point shape file (for surveyed structures), parcel data (if geospatial data describing the location of the parcels), or from the HAZUS database. The structure inventory is described by a series of attributes, damage category allows the user to aggregate like structures together (residential, commercial, industrial), occupancy type

allows the user to specify differences within a damage category (residential with or without basements, multiple stories, multiple family dwellings, masonry or wooden etc.), foundation heights, values, and population. The most rapid way of generating a structure inventory is to use the HAZUS database. The HAZUS database is a product generated by FEMA that represents the entire United States at the state, county, tract and census block level. The data represented consists of structures and characteristics about those structures, and population and characteristics of the population, the smallest geographic representation is the census block. HEC-FIA accesses the data at the census block level, extracts relevant information and creates a uniform grid based on structure density and creates individual structures at the vertices of the grid within the census block. FIA then distributes the population within the structure inventory based on building type. The building type is correlated to a quantity of households. (see figure 1) FIA then calculates the population for both day and night, and the proportion of the population that is over or under 65 for those two times of day (eq. 1). Once the total number of people is determined by census block it is divided by the total number of households, and then each structure receives the number of people based on how many households it contains. This process is intended to determine the population exposed during the day and the night since the population moves in and out or to different locations within the floodplain based on time of day. The HAZUS data is based on the US CENSUS and since that is only conducted once every ten years the population data can be inaccurate, to facilitate the process of updating that information HEC-FIA allows the user to define regions where population has fluctuated and by how much it has fluctuated to more accurately describe the exposed population.

- **Warning Methodologies**

To describe the human response to flood warning, HEC-FIA has used existing research that created a mathematical representation of response to warning issuance. The research was done by George Rogers and John Sorensen to analyze the response to warnings for chemical release, nuclear disaster, and other natural disasters. The general framework of the mathematical representation of this relationship is dependent upon what system is being used to relay the warning issuance (EAS, reverse 911, sirens, etc.) and what the population is doing at the time of the warning issuance. The formula represents the fraction of the population that is warned for any time step. In this framework warned means that the individual has heard and fully understood the warning that was issued. This distinction is important, because some warning methodologies are only an alert system, for instance sirens do a sufficient job to alert the public something is going on, but not much information describes the direct hazard that the warning is being used for. In those instances there must be a representation of how much time it takes for an individual to fully understand the threat and necessary reaction. A general framework is shown in figure 2. The mathematical formula is split into two portions, the first half of the equation describes the initial warning itself, and the second half describes the secondary warning process. When an individual is warned, they are able to warn other individuals at risk within the floodplain through any available methodology with the secondary warning process.

Once the warning has taken place, the population enters the mobilization portion of this process. Mobilization describes the time it takes for a person to react appropriately given a warning. After fully understanding the threat and required actions, individuals have to determine if the threat directly applies to them, and if it does, typically the individual will then take some time to gather any necessary items to take with them when they evacuate. The alternative name for this process would be the mulling process. This process is defined by a curve within HEC-FIA that shows the number of people who begin evacuation over time, generally the mobilization curve max will be no greater than 98% since there is a portion of the population who if given warning will refuse to take appropriate action. The warning curve and the mobilization curve are then combined through a process that takes the marginal amount of people who were warned in the previous timestep into the mobilization process, and so on. The combined mobilization curve ultimately describes the rate at which the population enters the evacuation network. This process is modeled individually at each structure, but is represented as a percentage of the total population for that given structure, therefore, the methodology is trying to suggest that the population is homogeneous, and reacts generally the same across the floodplain to the given warning.

Upon mobilization the individual enters the evacuation process. HEC-FIA simplifies this process and uses a straight line from the structure to the nearest safe location to represent the evacuation path. This path is followed at a user defined nominal velocity, so HEC-FIA calculates the distance of the line and multiplies the evacuation velocity times the distance of the line to come up with the time it takes for the individual to get to safety (safety is defined by less than 2 ft of water). Alternatively the user can define the time it takes for any structure to evacuate to safety.

- Assigning Fatality rates

From the warning process, evacuation outcomes are determined based on the arrival of 2 ft of water at the structure and the location they are evacuating to. These outcomes are either **cleared**, in that they reached the safe location prior to the water, **caught**, in that they evacuated from their structure but were caught along the way, and **not mobilized**, in that they either decided not to mobilize or were unable to given the arrival time of the water.

**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 structures are assigned to flood lethality zones based on maximum instantaneous depth times velocity, 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).

- a) For any structure: if the depth times velocity exceeds the RESCDam criteria for partial survivorship, the structure will receive either chance or compromised given maximum

depth, if the depth times velocity exceeds the RESCDam criteria for total destruction, the category is automatically determined to be Chance.

- b) For any structure: if structure totally survives and event maximum depth < 2 feet or less than the foundation height (fh) of structure, then no flood lethality zone assignment is made and the people are grouped with the Cleared evacuation category;
- c) If 1-story structure where the population is under 65:
  - i) if the structure totally survives and event maximum depth < fh + 13 feet then assign to Safe Zone, if structure partially survives, and maximum depth < fh + 13 ft then assign to compromised zone, if structure is totally destroyed, then assign to chance zone:
  - ii) if the structure totally survives or partially survives the event and event maximum depth  $\geq$  fh + 13 feet and < fh + 15 feet then assign to a Compromised Zone, if the structure is totally destroyed, then assign to chance zone;
  - iii) else event maximum depth  $\geq$  fh + 15 feet then assign to a Chance Zone.

For each additional story, add 9 feet to the depth criteria in c) to determine flood lethality zone. Depending on occupancy type the fatality rates for over 65 the lethality zone thresholds can be set lower.

Once the lethality zone is determined by each structure HEC-FIA applies the following average fatality rates based on the probability distributions of fatality rates for each Flood Lethality Zone described by McClelland and Bowles (2002). The lethality zones are intended to describe the environment at the time of the flood, and the probability of survivorship given that environment, general descriptions of the zones and associated fatality rates are shown below.

- a) *Chance Zones*: in which flood victims are typically swept downstream or trapped underwater, and survival depends largely on chance; that is, the apparently random occurrence of floating debris that can be clung to, getting washed to shore, or otherwise finding refuge safely. The historical fatality rate in Chance Zones ranges from about 38 percent to 100 percent, with an average rate over 91 percent.
- b) *Compromised Zones*: in which the available shelter has been severely damaged by the flood, increasing the exposure of flood victims to violent floodwaters. An example might be when the front of a house is torn away, exposing the rooms inside to flooding. The historical fatality rate in Compromised Zones ranges from zero to about 50 percent, with an average rate near 12 percent.
- c) *Safe Zones*: which are typically dry, exposed to relatively quiescent floodwaters, or exposed to shallow flooding unlikely to sweep people off their feet. Depending on the nature of the flood, examples might include the second floor of residences and sheltered backwater regions. Fatality rate in Safe Zones is virtually zero and averages 0.02 percent.

The entire probability distributions of fatality rates for each Flood Lethality Zone are used in HEC-FIA when the uncertainty analysis option is selected

### **Strengths/Weaknesses**

HEC-FIA attempts to take into account age, warning methodology, daily activity, effectiveness of warnings, vertical evacuation, and the dynamic nature of the flood. The strengths of this approach are the capability of distinguishing between geographic locations, population characteristics, warning system types and the built environment. Having the full floodwave described in a few summary grids helps HEC-FIA reduce the data to a minimal amount without losing the specificity of the hydraulic event. HEC-FIA has limitations when approaching the evacuation portion of the life loss equation. If there is a significant issue associated with traffic jams or the interaction of the population with the floodwave during evacuation, HEC-FIA may underestimate the life loss in the category of caught evacuating.

### **Conclusion**

HEC-FIA is a program that quickly assesses the potential for life loss of flood events, and gives insight into potential improvements within the flood plain either structural or nonstructural that can reduce the life loss potential. HEC-FIA may not be able to accurately portray the evacuation model, but it gives the user general information about the overall risk within the flood plain and is sufficient for most cases. A qualitative assessment of issues can be used to influence the modelers description of the consequence for a given event.

#### **2.2.4 Lifesim**

#### **2.2.5 Loss of life methods comparison and discussion**

##### **General comparison**

A comprehensive comparison of the various modelling approaches is included in table \* below.

|                                  | <b>1953 interpolated</b>                                    | <b>Katrina</b>                                              | <b>HEC FIA</b>                                                                              | <b>Lifesim</b>                                               |
|----------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|---------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| Application: flood types         | Levee breaching, river, coastal                             | Levee breaching, river, coastal                             | levee breaching, dam failure                                                                | levee breaching, dam failure                                 |
| Application                      | Regional and national risk assessment                       | Regional and national risk assessment                       | Planning purposes?                                                                          | Planning, More detailed analysis                             |
| Implemented                      | HISSTM                                                      | (Levee screening tool?)                                     | HEC-FIA                                                                                     | Lifesim                                                      |
| <b>Inputs</b>                    |                                                             |                                                             |                                                                                             |                                                              |
| Population data                  | inhabitants                                                 | Inhabitants                                                 | Day or night population                                                                     | Day or night population                                      |
| Main hydraulic Input data*       | d, v, w                                                     | D, v                                                        | D, v, w, t                                                                                  | D,v,w,t                                                      |
| Building vulnerability / shelter | - (building indirectly in breach zone)                      | - (indirectly in breach zone)                               | Degree of shelter included                                                                  | Degree of shelter included                                   |
| Shelter                          | Can be included as a separate fraction                      | Can be included as a separate fraction                      | Degree of shelter is included                                                               | Degree of shelter is included                                |
| Evacuation concept               | Evacuation before flood considered, given as input fraction | Evacuation before flood considered, given as input fraction | Includes warning and evacuation routine.                                                    | Includes warning and evacuation routine, incl road network   |
| Scale of input data              | Larger-scale (dike ring) population distribution            | Larger-scale (dike ring) population distribution            | Individual structure level                                                                  | Individual structures                                        |
| <b>Model concept</b>             |                                                             |                                                             |                                                                                             |                                                              |
| Type of modelling                | Static, empirical                                           | Static, empirical                                           | Static, based on distribution of people over zones                                          | Dynamic?                                                     |
| Empirical basis                  | 1953 Netherlands UK, 1959 flood in Japan                    | 2005, Katrina New Orleans                                   |                                                                                             | Various dam break floods                                     |
| Method: zones and states         | four zones: breach, rapid rise, transition, remaining       | Two zones: Breach, other                                    | 3 states: cleared, evacuating and not mobilizes, with 3 criteria: safe, compromised, chance | Dynamic model<br><br>Three states: safe, compromised, chance |
| Mortality rate calculation       | Continuous functions                                        | Continuous functions                                        | Step-wise functions                                                                         | Step-wise functions                                          |
| Main reference(s)                | Jonkman, 2007<br>Maaskant et al., 2009                      | Jonkman et al., 2009                                        | USACE, 2011                                                                                 | McClelland and Bowles, 1999, 2002; Aboelata, 2003            |

\*D – flood depth, v – flow velocity; w – rise rate; t – arrival time

## Comparison of mortality functions

The mortality functions that are implemented in the various methods are compared below. The HEC-FIA functions have been shown for a single story residence. Two figures are shown for two domains of water depth. In the Dutch method no effect of the rise rate is included up to water depths of 2.1m and one mortality function is used. For higher water depths various functions are used depending on the rise rate.

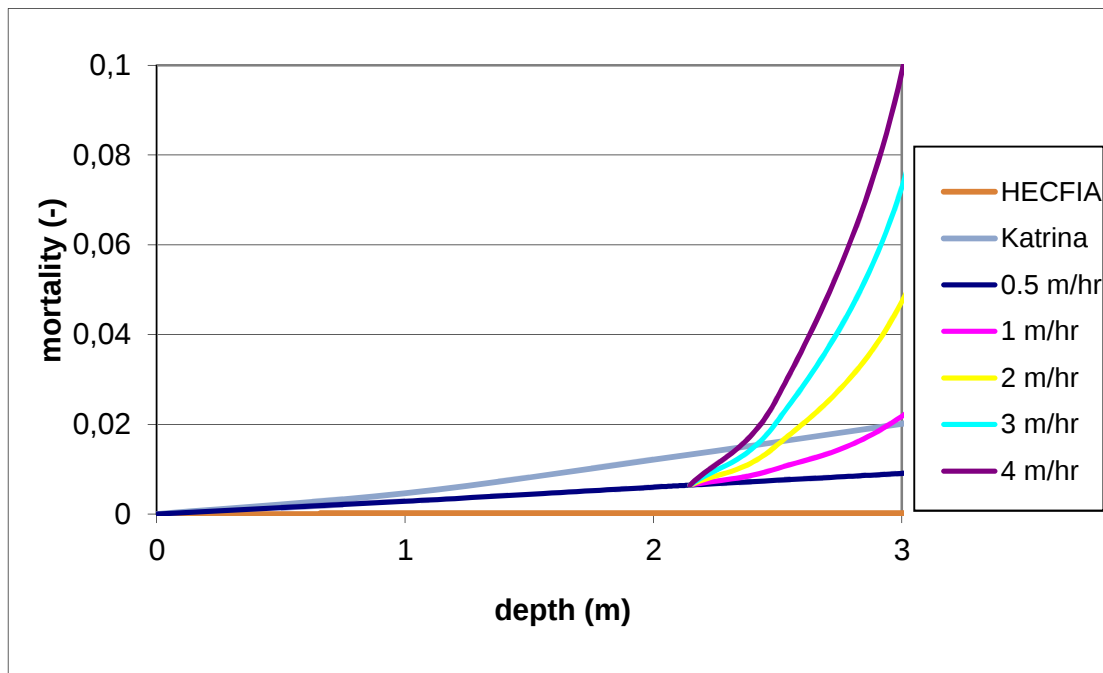
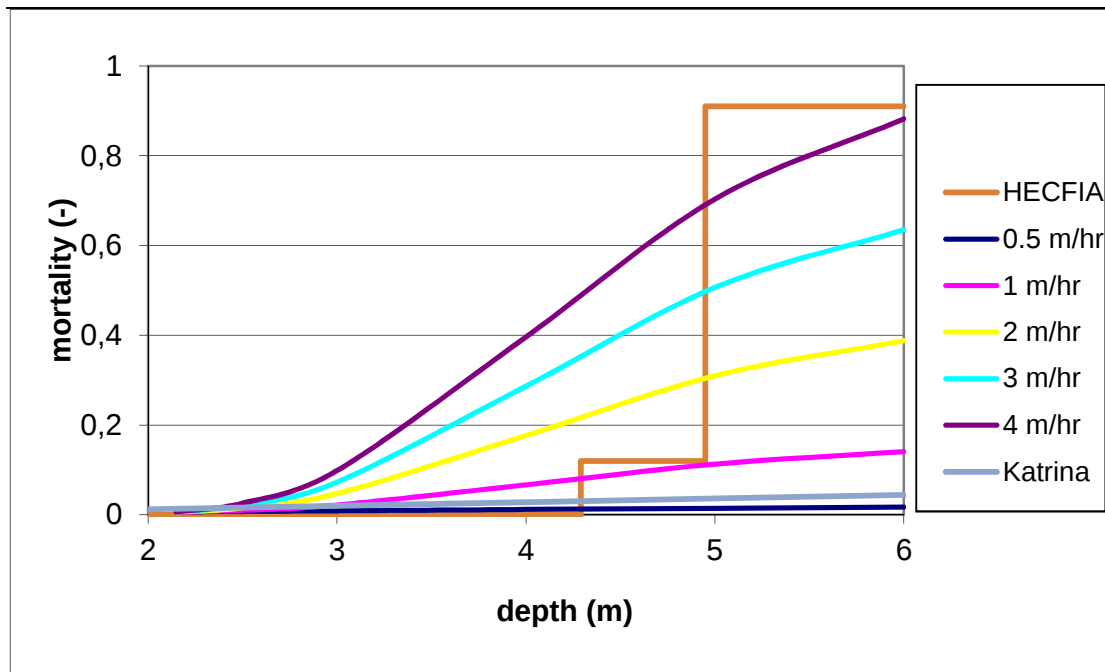


Figure 10: Comparison of the 1953 interpolated method, Katrina functions and HEC FIA.



For water depths up to 2m the Katrina method gives the highest mortality rate prediction, higher than the interpolated 1953 and HEC FIA method.

HEC FIA estimates a mortality fraction of 0.0002 up to depths of 4.3m (13 ft) for people in a one story building. This is lower than the mortality fractions from the interpolated 1953 and Katrina functions. It is not a fully valid comparison since the 1953 and Katrina functions will be applied to all the people present in the area, whereas the low mortality rate in HEC FIA will only be applied to people in a building. In HEC FIA people can also be in another “state”, for example evacuating, with a higher mortality rate.

For water depths higher than 2m, the interpolated 1953 functions for rise rates higher than 0.7m/hr give higher mortality fractions than the Katrina functions.

## Discussion

- Validation of the methods based on actual events is important:
  - Katrina
  - Other events (1953, Xynthia in France?)
  - A recent validation effort (di Mauro and de Bruijn, 2012) focused on the Canvey Island case study.
- Overall, differences in the outcomes that are obtained with various methods will largely depend on differences in flood characteristics (relative importance of rise rate), and the assumptions with respect to the number of people evacuated or in a certain zone in HEC FIA / Lifesim. Further comparison case studies are included in the next sections to be able to make an actual comparison.

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## 2.3 Dutch Evacuation and Evacuaid approach (Kolen)

### 2.3.1 Evacuation approach implemented in HEC FIA

### 2.3.2 Evacuation approach implemented in Lifesim

### 2.3.3 Evacuation analysis applied in the Netherlands (deterministic)

### 2.3.4 Evacuaid, probabilistic evacuation approach

### 2.3.5 Evacuation methods comparison (Kolen)

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## Appendix 2.1: Summary of the interpolated mortality functions based on the 1953 floods in the Netherlands

Breach zone:

$$F_{D,B} = 1 \quad \text{if} \quad dv \geq 7 \text{ m}^2 / \text{s} \quad \text{and} \quad v \geq 2 \text{ m/s}$$

Mortality in the zone with rapidly rising waters

$$F_{D,Rise}(d) = \Phi_N \left( \frac{\ln(d) - \mu_N}{\sigma_N} \right)$$

$$\mu_N = 1.46 \quad \sigma_N = 0.28$$

$$\text{if} \quad (d \geq 2.1 \text{ m} \quad \text{and} \quad w \geq 4 \text{ m/hr}) \quad \text{and} \quad (dv < 7 \text{ m}^2 / \text{s} \quad \text{or} \quad d < 2 \text{ m/s})$$

Mortality in the transition zone

For rise rates between  $0.5 \text{ m/hr} \leq w < 4 \text{ m/hr}$  the following function is used. ( $F_{D,remain}$  refers to the mortality function for the remaining zone below).

$$F_D = F_{D,Remain} + (w - 0.5) \frac{F_{D,Rise} - F_{D,Remain}}{3.5}$$

$$\text{if} \quad (d \geq 2.1 \text{ m} \quad \text{and} \quad 0.5 \text{ m/hr} \leq w < 4 \text{ m/hr}) \quad \text{and} \quad (dv < 7 \text{ m}^2 / \text{s} \quad \text{or} \quad v < 2 \text{ m/s})$$

Mortality in the remaining zone

For the remaining zone the following function can be applied:

$$F_{D,Remain}(d) = \Phi_N \left( \frac{\ln(d) - \mu_N}{\sigma_N} \right)$$

$$\mu_N = 7.60 \quad \sigma_N = 2.75$$

$$\text{if} \quad (w < 0.5 \text{ m/hr} \quad \text{or} \quad (w \geq 0.5 \text{ m/hr} \quad \text{and} \quad d < 2.1 \text{ m})) \quad \text{and} \quad (dv < 7 \text{ m}^2 / \text{s} \quad \text{or} \quad v < 2 \text{ m/s})$$

The figure below shows which function can be used for certain hydraulic conditions.

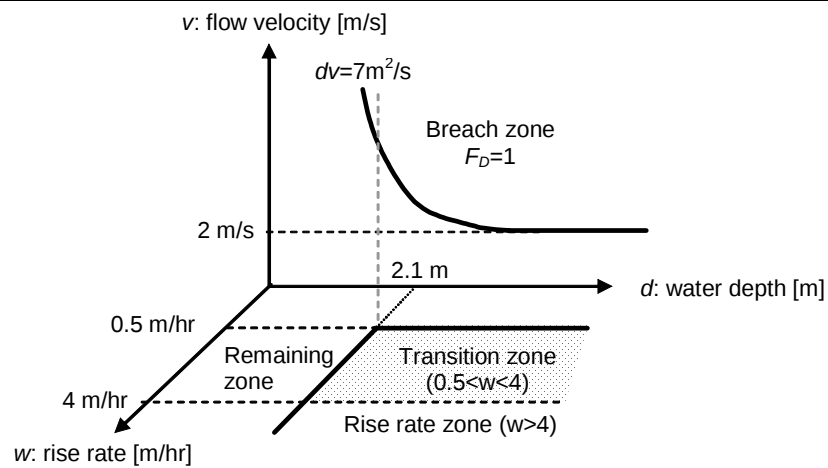


Figure: Area of application of the various mortality functions as a function of depth, rise rate and flow velocity.

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Appendix 3: Preliminary results of life loss analysis for the Natomas Basin



Loss of Life Case study Natomas

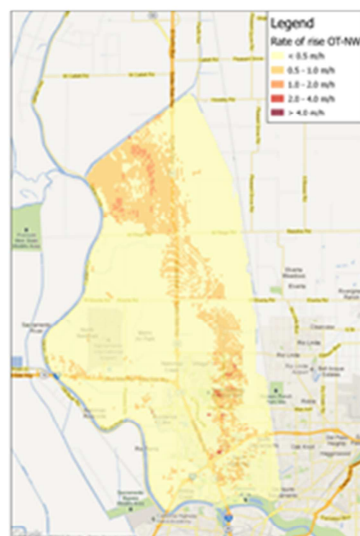
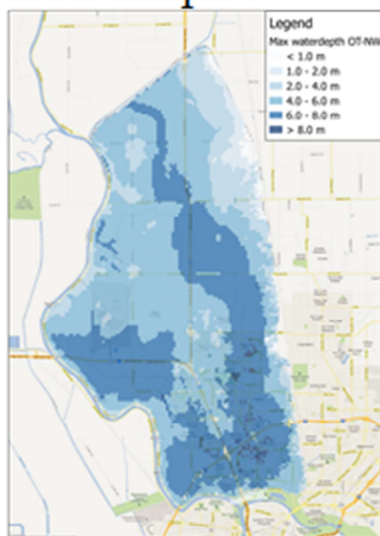
Conference Call 11<sup>th</sup> December 2012

## Progress Natomas

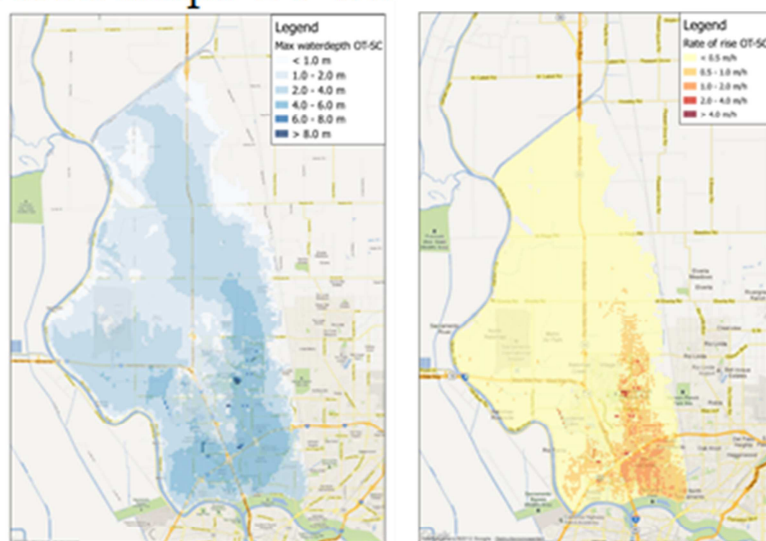
- Loss of life analysis ready
- Two Flood scenarios:
  - Overtopping and after a breach
  - Sacramento river - North west (red arrow)
  - American river (blue arrow)
- Results of Loss of Life analysis are presented in the following slides



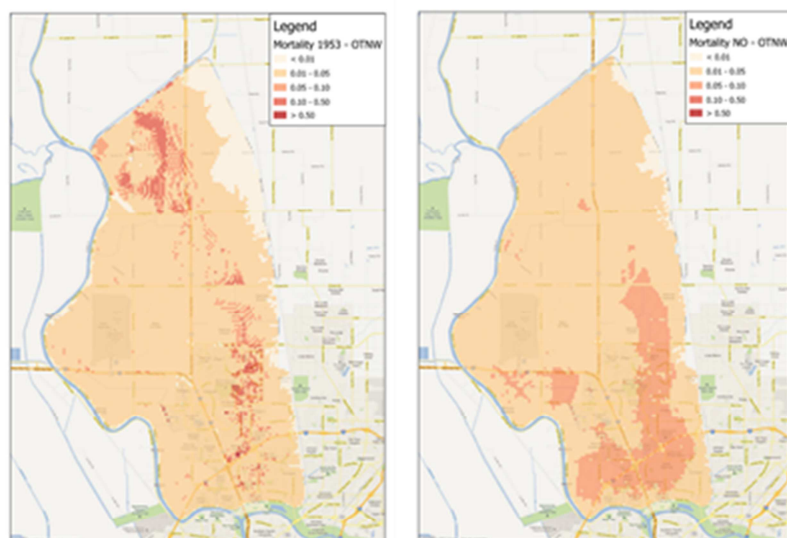
## Flood maps OT-NW



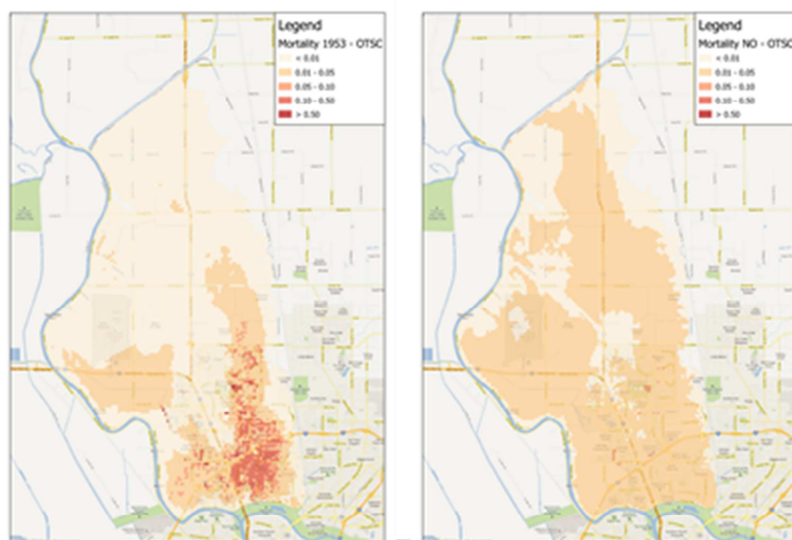
## Flood maps OT-SC



## Mortality OT-NW

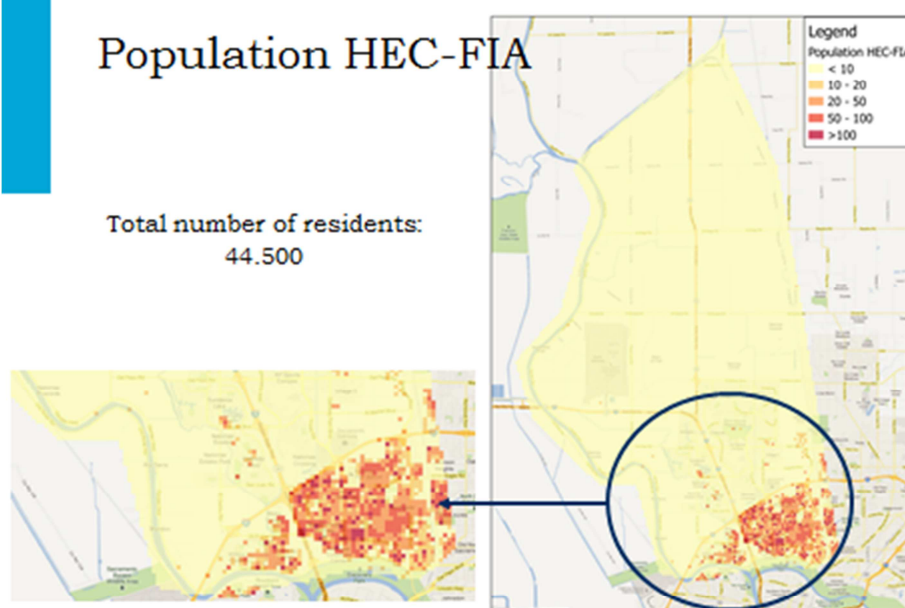


## Mortality OT-SC

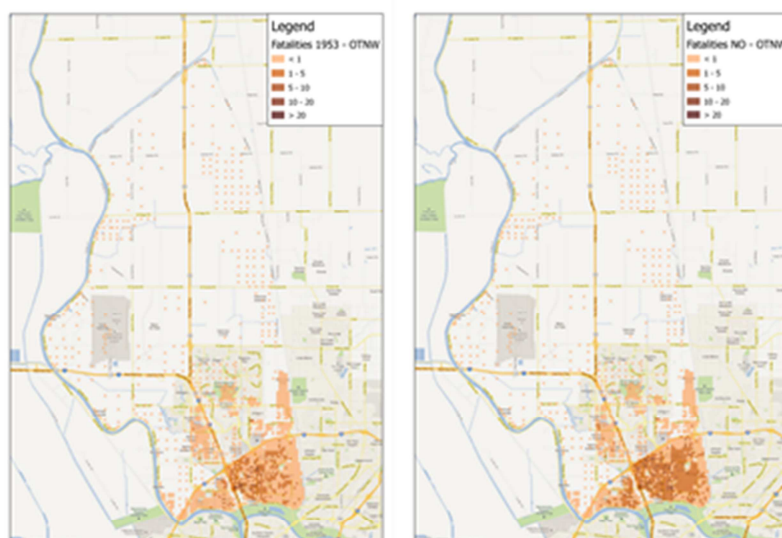


## Population HEC-FIA

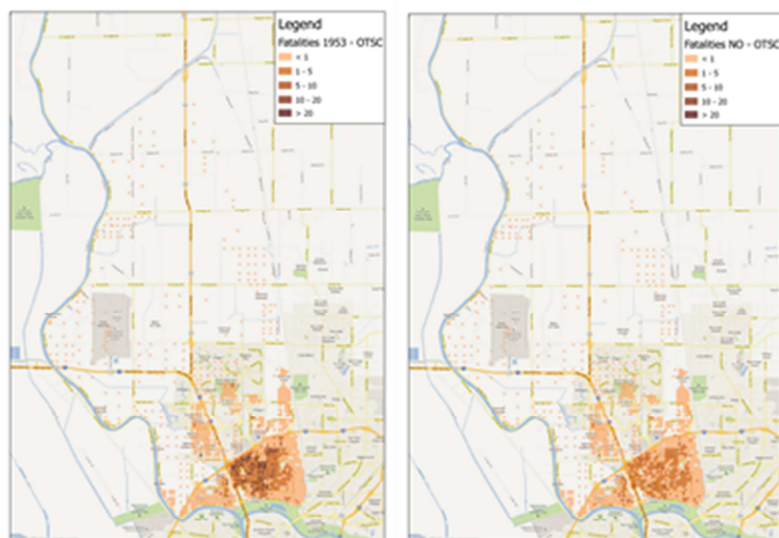
Total number of residents:  
44.500



## Fatalities OT-NW



## Fatalities OT-SC

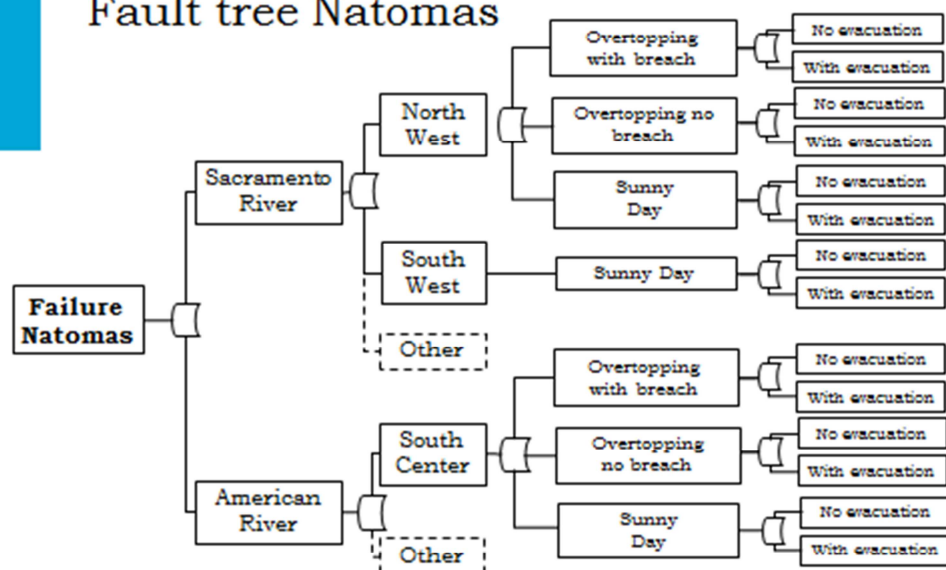


## Number of fatalities

| BREACH |       | FATALITIES JONKMAN |             |
|--------|-------|--------------------|-------------|
|        |       | 1953               | NEW ORLEANS |
| NW     | OT-NW | 909                | 1811        |
|        | SD-NW | 1103               | 1580        |
|        | SL-NW | 0.76               | 1.12        |
| SC     | OT-SC | 2815               | 1100        |
|        | SD-SC | 1550               | 1110        |
|        | SL-SC | 307                | 445         |
| SW     | SD-SW | 361                | 665         |

OT = Overtopping with breach  
SD = Sunny Day  
SL = Overtopping without breach

## Fault tree Natomas



## Progress Herbert Hoover Dike

- Loss of life model Jonkman is ready to use
- Two flood scenarios:
  - Single breach at Lake Okeechobee
    - Water level Lake Okeechobee 20 FT
    - Water level Lake Okeechobee 30 FT
  - Single breach at Belle Glade
    - Water level Lake Okeechobee 20 FT
    - Water level Lake Okeechobee 30 FT
- Flood simulations (MIKE21 model) will be provided by USACE
  - max water depth
  - max rate of rise
  - max velocity
- Population grid based on HEC-FIA data
  - grid cell size population grid equivalent to grid cell size hydraulic data



## Progress New Orleans

- SOBEK model is available
- Three Flood Simulations:
  - Multiple breach at Lake Pontchartrain due to storm surge (green arrows)
    - Metro Bowl
    - East Bowl
  - Multiple breach at Lake Borgne due to storm surge (red arrows)
    - St. Bernard Bowl
    - East Bowl
  - Single breach Mississippi River due to high discharge (blue arrows)
    - Metro Bowl
- Boundary conditions water level:
  - 1/200 per year

