LIFESim: A Tool for Estimating and Reducing Life-Loss Resulting from Dam and Levee Failures

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Abstract

LIFESim is a modular, spatially-distributed, dynamic simulation system for estimating potential life loss from natural and dam and levee failure floods. LIFESim can be used for dam safety risk assessment and by dam owners and local authority emergency managers to explore options for improving the effectiveness of emergency planning and response. Development of LIFESim has been sponsored by the U.S. Army Corps of Engineers (USACE) and the Australian National Committee on Large Dams (ANCOLD).

The LIFESim model has been applied to estimate fatalities resulting from a wide range of levee failure scenarios in Greater New Orleans and for several dams under a range of failure and exposure scenarios. The USACE Hydrologic Engineering Center (HEC) is applying LIFESim and planning to incorporate it into future HEC software. This paper introduces the LIFESim model and demonstrates its capabilities.

Introduction

Dam safety risk assessment requires credible life-loss estimates from natural and dam-failure floods. LIFESim is a spatially-distributed dynamic simulation modeling system for estimating potential life loss. It has been formulated to overcome the limitations of the purely empirical life-loss estimation approaches; these are detailed by McClelland and Bowles [2002] and summarized by Aboelata et al [2003]. LIFESim considers evacuation, detailed flood dynamics, loss of shelter and historically-based life loss. LIFESim can be used to provide inputs for dam safety risk assessment and to explore options for improving the effectiveness of a dam owner's emergency plans or a local authority's response plans. Development of LIFESim has been sponsored mainly by the USACE and ANCOLD.

LIFESim has been formulated using an underlying development philosophy that emphasizes including 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: 1) Loss of Shelter, including prediction of building performance; 2) Warning and Evacuation; and 3) Loss of Life, which is based on scale-independent empirical relationships developed by McClelland and Bowles [2000]. Estimated flooding conditions are obtained from an external dam break flood routing model. LIFESim can be run in Deterministic or Uncertainty Modes. The Uncertainty Mode provides estimates of life loss and other variables relating to warning and evacuation effectiveness, as probability distributions.

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Model Development

The first phase of our research to develop LIFESim involved the collection and characterization of case histories of flood events and the people in those floods [McClelland and Bowles 2000 and 2002]. The understanding and insights that resulted from this work are the foundation on which LIFESim is built.

Aboelata et al [2004b] demonstrated a preliminary version of the Deterministic Mode LIFESim for flood-induced and sunny day dam failures. The two cases differed in warning and evacuation characteristics with a two-stage evacuation of areas affected by spillway discharges and dam failure being considered for the flood case. Aboelata et al [2004a] demonstrated a more advanced version of the Deterministic Mode for sudden and delayed earthquake dam failures for an existing warning and evacuation system and for an improved system. In addition, results from a preliminary version of the Uncertainty Mode were illustrated and comparisons were made with the empirical Graham [1999] method of estimating life loss.

Aboelata et al [2004a] described and demonstrated a dynamic transportation model as an addition to the Warning and Evacuation Module of LIFESim. This module simulates the spatial redistribution of the threatened population from their initial locations, at the time that an evacuation warning is issued, to their new locations at the time of arrival of the flood throughout a study area located downstream of a dam.

Aboelata and Bowles [2006] described and demonstrated an additional module for extracting detailed data from the HAZUS-MH database [FEMA 2003]. This module improved the quality and spatial variability of structures and population data. A sensitivity study demonstrated the critical role that warning initiation time plays in the opportunity for evacuation and in determining fatality rates. A comparison of the Deterministic and Uncertainty Mode results clearly illustrates that best estimate inputs in the Deterministic Mode do not necessarily lead to results that are close to the most likely estimates of life loss that are obtained from the Uncertainty Mode; and hence the importance of considering uncertainties in life-loss estimation.

While LIFESim is being applied, it is also undergoing a process of continual improvement. Some of these additions and modifications to the model capabilities are discussed later in this paper.

Model Overview

LIFESim is structured as a modular modeling system built around a database. Each module exchanges data with other modules through the database, which includes various geographic information system (GIS) layers and tables. LIFESim utilizes readily-available GIS information on road layout, population and buildings obtained from Census and HAZUS MH data. Default relationships and values are provided for many other inputs.

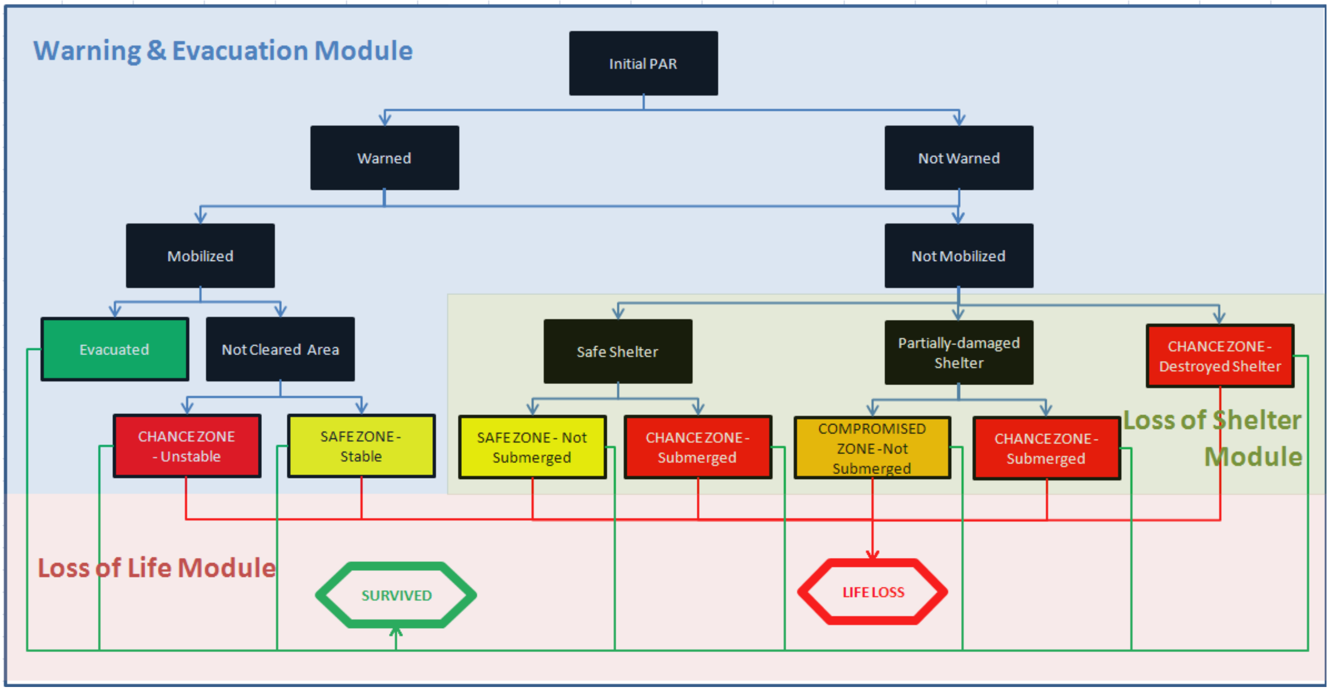

Figure 1. Schematic of the LIFESim Approach to Life-loss Estimation (Bowles 2007)

Figure 1 is a schematic of the LIFESim approach to life-loss estimation. The four major modules that comprise LIFESim are as follows:

1) Dam Break Flood Routing Module – interfaces with an existing dam-break flood routing model, such as DAMBRK [BOSS 1999] or HEC-RAS [HEC 2002], to provide a set of grids representing water depth and flow velocities over the entire study area and throughout the duration of the flood event.
2) 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.
3) Warning and Evacuation Module - simulates the spatial redistribution of the population at risk (Par) following initiation of a warning.
4) Loss of Life Module – makes life-loss estimates using life-loss probability distributions developed by McClelland and Bowles [2000 and 2002], modified in Aboelata et al [2004a] and presented later in this paper in the *Loss–of-Life Module* subsection.

LIFESim is designed to be applied to a set of event-exposure scenarios. Events include different dam failure modes and breach locations, no-failure flooding and different flood severities. Exposure cases can include different seasons, day/night and weekend/weekday conditions affecting the size and distribution of the population at risk and various aspects of the warning and evacuation system performance. The simulation period for each LIFESim model run should commence with the initiation of the first evacuation warning and should continue to the time of occurrence of the maximum peak of the hydrograph of the flood event at the most downstream consequence center that is considered.

The Uncertainty Mode of LIFESim propagates input uncertainties through the model to provide probability distributions of the uncertainties in life-loss estimates.

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 the flooding area for which historical fatality-rate probability distributions were estimated by McClelland and Bowles [2000 and 2002]. Flood (lethality) zones distinguish physical flood environments in which historical rates of life loss have distinctly differed. Three flood zones are physically defined by McClelland and Bowles [2000 and 2002] by the interplay between available shelter and local flood depths and velocities, summarized as follows:

- *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. Historical fatality rates range from about 50 percent to 100 percent, with an average rate of about 90 percent.
- *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 rooms inside a building experience rapidly-moving shoulder-height flood water. Historical fatality rates range from zero to about 50 percent, with an average rate of about 10 percent.
- *Safe zones* are typically dry, exposed to relatively quiescent floodwaters, or exposed to shallow flooding unlikely to sweep people off their feet. Examples might include the second floor of residences and sheltered backwater regions. Historical fatality rates are virtually zero.

Use of homogeneous flood zones by McClelland and Bowles [2000 and 2002] lead to a scale-independent approach to estimating fatality rates for use in LIFESim and which extracts more information from available case studies.

Warning and Evacuation Module

The Warning and Evacuation Module spatially redistributes the Par from its initial distribution by Par type at the time that a warning is issued, to a new distribution with assigned flood zone categories at the time of arrival of the flood. It does this through simulation of the warning dissemination, mobilization and evacuation-transportation processes. Figure 2 is a schematic of an example of event sequences and their associated time lines for the three types of organizational entities for a typical warning and evacuation process as represented in LIFESim. It is summarized below:

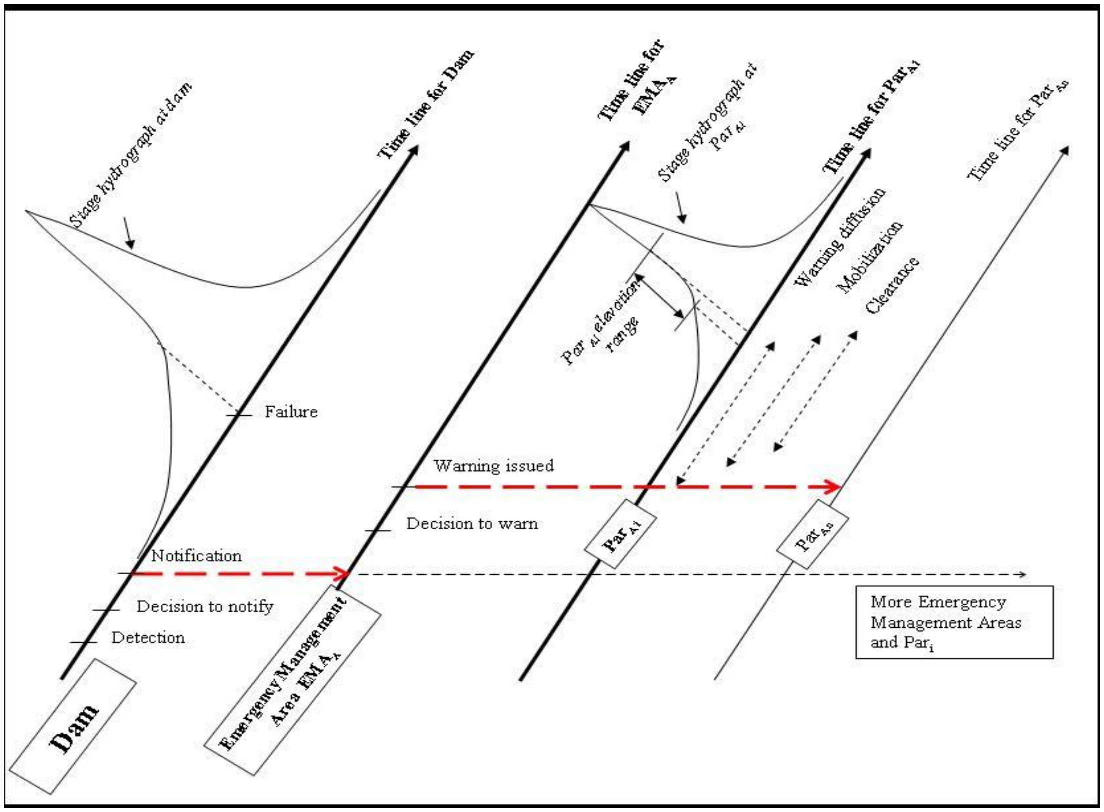

Figure 2. Time lines for events in warning and evacuation processes.

- *Dam and dam owner/operator events:* detection of a failure or potential failure; decision to notify the authorities in each emergency management area; notification; and dam failure[3].
- *Emergency management area (EMA) events:* receiving a notification from the dam owner; decision to warn the public; and initiation of formal warnings.
- *subPar (Par_i) events:* receiving a warning; mobilizing; traveling across and clearing the flooding area; and flood arrival shown by a stage hydrograph. More than one EMA may exist below a dam and numerous subPar are located within each EMAj.

The three major components in the Warning and Evacuation Module are summarized in the following subsections.

Warning: The warning initiation time is the time at which an evacuation warning is first issued to the Par. It is defined to be positive if the warning is issued after dam failure occurs, or to be negative if the warning is issued before failure occurs. Proper consideration of staged warnings using LIFESim [Aboelata et al 2003] as spillway discharges increase for both no-failure floods and the pre-failure phase of flood-induced failure floods is important for estimation of life loss for these cases and for the estimation of incremental life loss for flood-induced failures.

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[3] The order of these events may vary. For example, detection may not take place until after failure. In some circumstances, the detection, decision and notification steps may be performed by someone other than the dam owner's representative.

The rate at which the warning is received throughout an EMA is represented in LIFESim using a warning diffusion curve, which is the cumulative percentage of the Par that receives the warning message versus time, starting at the warning initiation time. The overall area to be warned may be divided into several emergency planning zones (EPZs), possibly with different warning initiation times. Empirical warning diffusion curves are available in LIFESim for a range of different types of warning systems and different time-of-day activities. The use of LIFESim to compare the effectiveness of an existing warning and evacuation system and an improved system was demonstrated by Aboelata et al [2004b].

Mobilization: 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 a cumulative percentage of the warned Par that starts moving away from the area of potential flooding towards emergency shelters or other safe destinations.

At the time of arrival of the flood at a particular location, some people may remain in buildings. This would include people who choose to evacuate vertically in buildings, those who did not receive the warning and those who received the warning but decided not to mobilize, did not have the physical capability to evacuate, or did not have enough time to mobilize before outside conditions became unsafe.

Evacuation-Transportation: This process commences with mobilization and ends with either clearance of the flooding area or entrapment if the evacuation route becomes blocked by flooding. People who clear the flooding area are assigned to a “safe” flood zone and people who are trapped on the road are assigned to a flood zone that depends on their mode of evacuation and the most severe flooding conditions for the event. Three modes of evacuation are included in LIFESim: cars, sports utility vehicles (SUV’s) and pedestrians.

The Greenshield [1935] transportation model is used to represent the effects of traffic density and road capacity on vehicle speed. The original model was modified to represent congestion and traffic jams, as described in Aboelata [2005], by introducing a minimum “stop-and-go” speed (Vjam) if the jam density (Djam) for a road class is exceeded.

Census data is used to assign each road segment to a road class and to specify its length and interconnectivity with other road segments. Each road class is assigned default values of the number of lanes, free flow speed (ffs), Djam and Vjam based on the Highway Capacity Manual (HCM) [TRB 2000], although these can be overridden if more detailed information is available for the road system. Contraflow can be represented by doubling the number of lanes assigned to road classes.

People who reach a safe destination at the boundary of the area that becomes flooded are considered as the “cleared” group. The locations of safe destinations can include “islands” of higher ground or buildings, which is considered to be capable of withstanding the anticipated flooding, inside the flooding area. Therefore, safe destination locations must be carefully defined by the user to represent the expected evacuation situation. Designated routes in evacuation traffic management plans should be used to the degree that it is expected that these would be used; which might be expected to depend on factors such as the effectiveness of community information campaigns, the credibility of emergency planners in the community, the inclusion of clear evacuation route instructions in warning messages and the existence of sufficient warning time to allow the police to direct traffic during an evacuation. As illustrated by Aboelata et al [2004a], alternative safe destination locations can be considered to evaluate alternative evacuation strategies.

Loss–of-Life Module

Based on the assigned flood zone categories, life-loss estimates are made using life-loss probability distributions developed by McClelland and Bowles [2000], updated Aboelata et al [2003] and displayed in Figure 3.

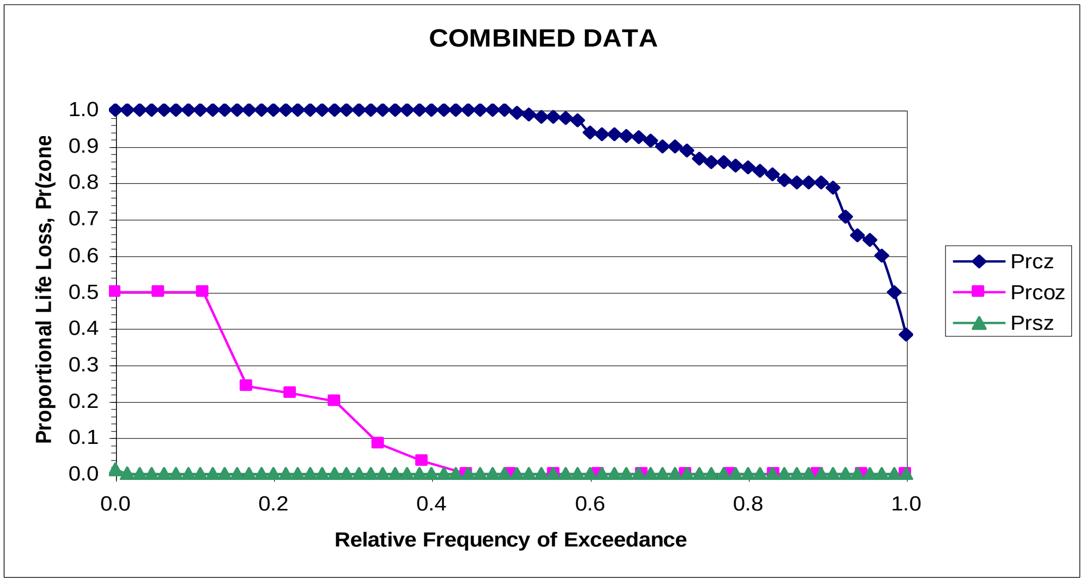

Figure 3. Probability distributions for fatality rates for each flood zone [Aboelata et al, 2003].

Uncertainty Mode

The Uncertainty Mode of LIFESim propagates model parameter and input uncertainties through the model to provide probability distributions of the uncertainties in life-loss estimates. These are epistemic or knowledge uncertainties. Aleatory uncertainties or natural variabilities due to factors such the time-of-the day and season of the year are handled by making a set of runs to represent these speared exposure conditions. The resulting distributions of life loss can be combined with estimates of the uncertainties in other risk assessment inputs, to obtain estimates of uncertainties in risk assessment results and then to make evaluations against tolerable risk guidelines. This approach has been illustrated by Chauhan and Bowles [2001 and 2004].

Model Applications

LIFESim model applications have been divided into two main phases. The first phase was model testing phase, which was carried out during preliminary prototype development and proof-of-concept demonstration. The second phase is the model application phase in which the model is now being used as a tool for estimating life loss from floods. In both cases the data simply do not exist for a comprehensive calibration and validation of LIFESim. This, however, is not unusual in the field of engineering analysis for dam safety in such areas as estimation of probable maximum floods and seismic stability analysis. Instead we depend on all the available information that we have from our analysis of case histories to critically evaluate model performance.

Model Testing Phase

Model development and validation was conducted using data for the physical settings of actual dams and downstream communities, but the range of failure conditions, exposure conditions and warning scenarios was varied to thoroughly test LIFESim over a wide range of conditions. In Aboelata [2005] and Aboelata and Bowles [2006], LIFESim was demonstrated using an anonymous dam failure case for two communities. The first community is in a rural setting with a maximum population of about 3,500 located between 5 and 8 miles from the dam. The second community is much larger with population of about 200,000 located about 40 miles downstream from the same dam. Deterministic, uncertainty and sensitivity analyses were performed using sunny-day dam failure scenarios with a short warning time for the first community and relatively long warning time for the second community. Illustrative model results included the following:

- Percentage warned per census block.
- Percent mobilized per census block.
- Fatality rate per census block.
- Number of people using each road segment for evacuation.
- Time from warning initiation until road segments are blocked by the flood.
- Total time when road segments become jammed by too many vehicles for the road capacity.
- Time from warning initiation to blocking of road segments by the flood.
- Number of people trapped in vehicles and on foot per road segment.
- Fatalities in vehicles and on foot per road segment.

Model Application Phase

Hurricane Katrina Life-Loss Modeling:

The USACE Interagency Performance Evaluation Task (IPET) Force, Task 9, included a consequences assessment for the human health, safety, social, cultural and economic impacts associated with future hurricane-related flood events in the greater New Orleans, Louisiana study area. The IPET consequence assessment was based on observed impacts associated with Hurricane Katrina, which occurred in August 2005. This LIFESim application is described in Stedge et al [2006] and USACE [2007].

The objective of this application was to estimate loss of life associated with hurricane-related flood events that may affect the greater New Orleans area in the future. Potential loss-of-life estimates were limited to the 27 drainage basins making up the New Orleans hurricane protection system (Figure 4). Loss of life was estimated for flooding corresponding to two demographic and structures base conditions. First, loss of life associated with all flood levels given the population and housing stock that existed prior to Hurricane Katrina was estimated. These results were helpful in IPET's forensic study of the impact of Hurricane Katrina and in understanding how the effects might have been different had the flood protection system behaved differently. Second, loss of life was estimated for a range of flood levels given the population and housing stock that were expected to exist in June 2006 at the start of the hurricane season following Katrina. These results helped to understand the residual risk in 2006 and how these risks could be reduced in the future.

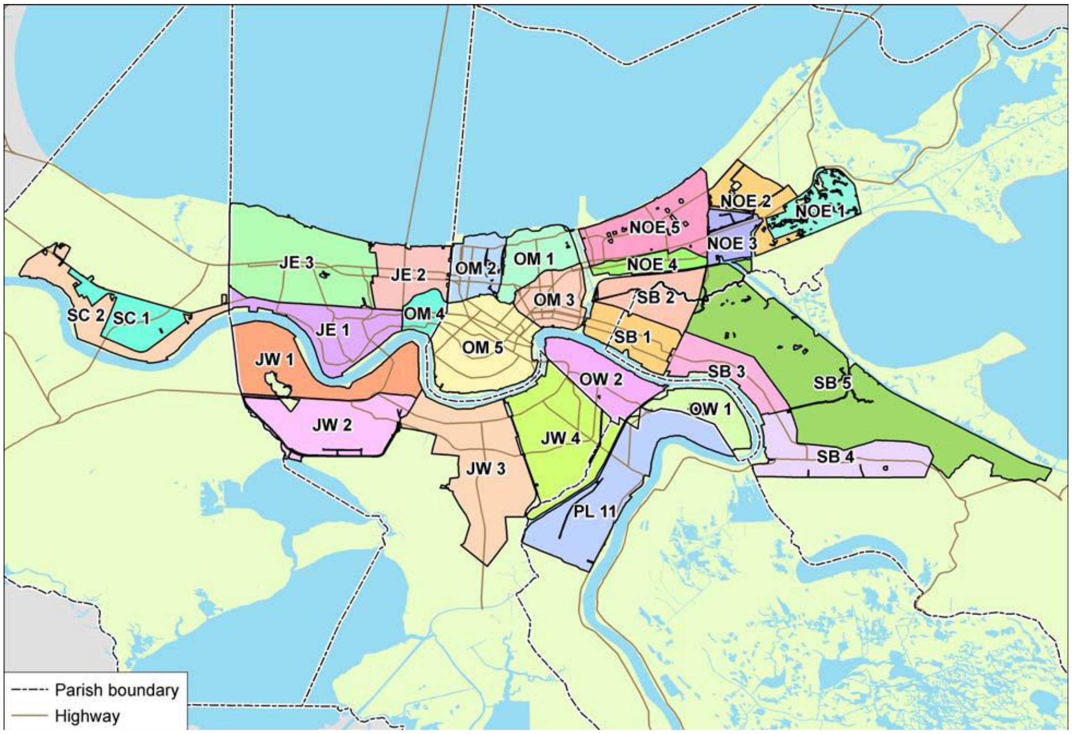

Figure 4. Drainage Basins of The Greater New Orleans Study Area [Stedge et al 2006]

For the IPET application of LIFESim the spatial extent of the greater New Orleans study area comprised a five parish region, namely: Jefferson, Orleans, Plaquemines, Saint Bernard and Saint Charles. The modeling approach was a two-step process. First, LIFESim model was used to estimate the vertical distribution of the population in the flooded areas in relation to the depth of flooding. Then, these vertical distribution estimates were imported into a Monte Carlo Uncertainty Model to estimate the distribution of loss of life with consideration given to uncertainty in the following:

- Evacuation rate.
- Rescue efficiency in the safe flood (lethality) zone.
- Rescue efficiency in the compromised or chance flood (lethality) zones.
- Fatality rate in the safe flood (lethality) zone based on Figure 3.
- Fatality rate in the compromised flood (lethality) zone based on Figure 3.
- Fatality rate in the chance flood (lethality) zone based on Figure 3.

The difference in nature between a dam break and a hurricane-related flood necessitated some additional assumptions for the model as well as elimination of some LIFESim functions. The following list describes the adjustments made to the LIFESim model to simulate Hurricane Katrina and future hurricane events:

- In the case of Hurricane Katrina, sufficient warning was given long before hurricane landfall (estimated to be as long as 50 hours in advance), such that the evacuation dynamics have no effect. Therefore the Warning and Evacuation Module did not need to be used.
- Loss-of-shelter in LIFESim depends mainly on building damage and submergence. Based on site investigations, the major cause of life loss in New Orleans appeared to be submergence of buildings. During Hurricane Katrina, most life loss occurred in areas not adjacent to levee breaks where flow velocities were too low to play a role in building damage. Therefore, in this study, loss of shelter is calculated based on only the submergence consideration, which is water depth relative to floor elevation at each habitable building level and for an additional loft or roof level.
- For the hurricane-related flood events, it was assumed that all people who did not evacuate the area, moved vertically to the highest habitable level of the building. In addition, it was further assumed that all people under the age of 65 years can climb to a higher level such as an attic or roof.
- The original LIFESim model assumed a fixed value for the average first floor level. Data was available for the greater New Orleans area on the average first floor level per Census block. The LIFESim model was modified to accommodate variable first floor level elevations for added accuracy.
- The threshold event maximum water depths associated with each flood (lethality) zone were estimated through a calibration process under the assumption that all buildings stayed intact with no damage. The three flood (lethality) zones were further modified to account for the disproportional impacts to populations over the age of 65 years old [see Figure 5].
- Another flood zone category was added to account for the number of people within the flooded area who can evacuate without any need for rescue. The people in the *walk-away* flood zone are those in areas where water depth does not exceed two-feet above the ground surface.

The LIFESim model was run at event-maximum flood inundation elevations in two-foot increments for each drainage basin from the lowest elevation up to 36 feet above sea level for the estimated evacuation rate and rescue efficiencies considered in the Monte Carlo model. This range of cases provided accuracy in calculating the effect of water depth on loss of shelter (submergence) across the four flood (lethality) zones. LIFESim generated a set of two-foot interval water surface grids, beginning at the lowest elevation point in each drainage basin, and filled the drainage basin with flood water two vertical feet at a time through simulation.

Figures 6 and 7 display the flood stage–fatality results for the New Orleans East drainage basin. The flood stage is defined in terms of the high water elevation. Figure 6 provides the results for the pre-Katrina conditions and Figure 7 shows the results for the post-Katrina (June 2006) conditions. Each graph provides the expected or median estimate of the number of fatalities at each elevation as well as the 90th percent confidence interval shown by the 5th and 95th percentiles.

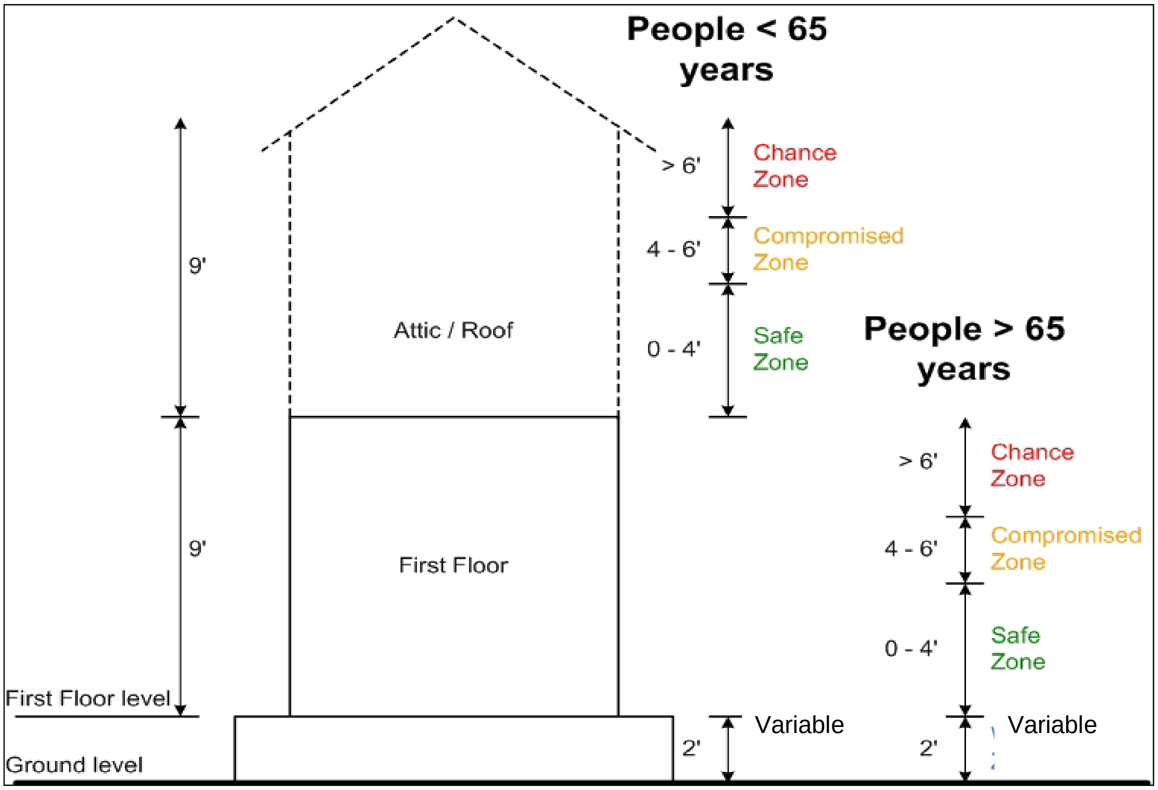

Figure 5. Modified Building Submergence Criteria [IPET 2006]

These life-loss results can be used for understanding the risks associated with future hurricane events. For each hurricane scenario, an estimate of the flood elevation that would be expected in each drainage basin can be obtained from other sources. Using this flood elevation estimate, the fatality estimates can be related to each potential hurricane event. Along with information on the likelihood of each hurricane scenario, the overall residual fatality risk in the New Orleans area as well as the risk of fatalities under different assumptions about the storm protection system can be estimated. However, the estimated evacuation rate and rescue efficiencies used in the Monte Carlo model would need to be updated to represent any changes that may have affected these since 2006.

Other LIFESim Modifications

LIFESim has been applied to support other dam safety risk assessment studies where some model modifications and enhancements were necessary to accommodate site-specific conditions. Although results from these studies cannot be published, the following sections describe some of the model improvements that have been made recently to LIFESim.

Structure Inventory Data:

If a detailed structure inventory data are available then they can be used instead of data from the HAZUS-MH database. A new procedure was added to LIFESim to use detailed structure inventory in conjunction with other HAZUS-MH data to provide LIFESim with the required structure data and associated population and activity data.

Using detailed structure inventory data has some advantages over using HAZUS-MH data. The detailed structure data provides the exact locations for each structure rather assuming a uniform spatial distribution of each type of structure over each census block such that water depth and flow velocity are specified for each structure. Population data estimated from HAZUS-MH database can also be updated if the structure inventory data post-date the latest HAZUS MH data based on the change in the number of households.

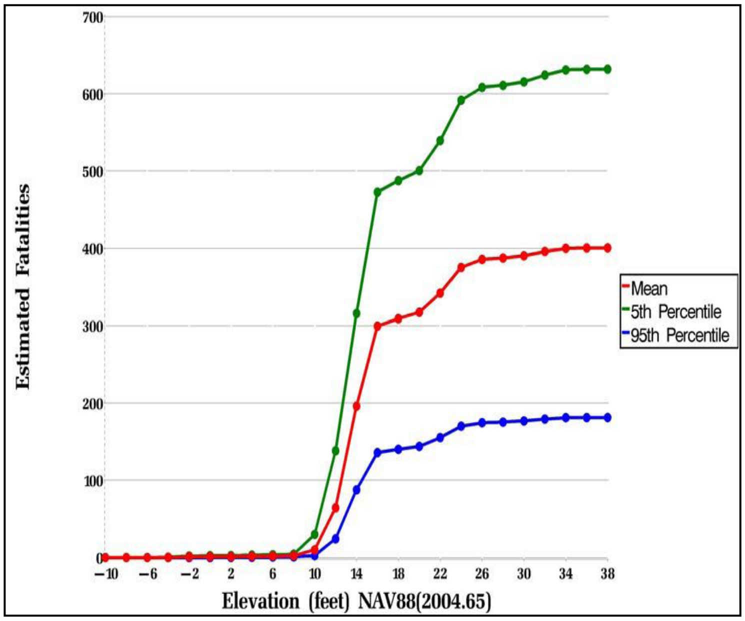

Figure 6. Pre- Katrina Model Results for New Orleans East Drainage Basin 2 [IPET 2006]

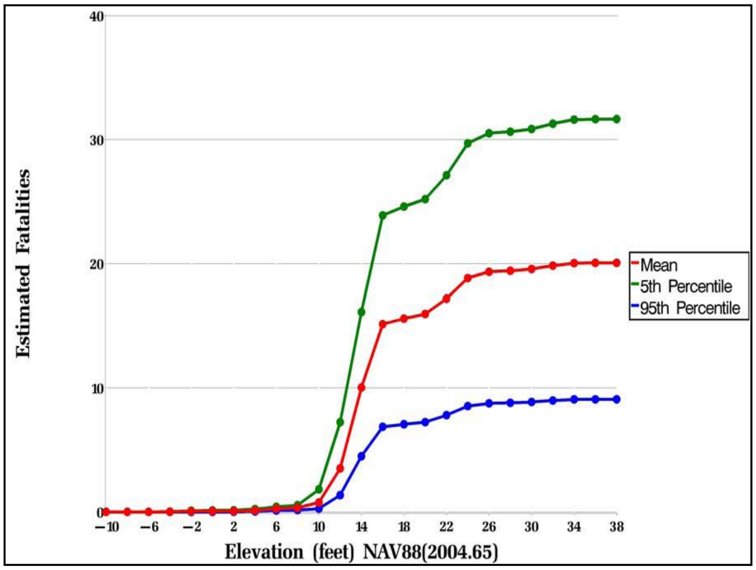

Figure 7. Post-Katrina Model Results for New Orleans East Drainage Basin 2 [IPET 2006]

User-defined Warning System:

The original formulation of LIFESim included six different warning systems covering some commonly-used systems consider by Rogers (1988). Changes in technology, such as the widespread use of cell phones and reverse-911 dialing systems are not included amongst the systems originally covered. These are now included through the addition of three user-defined warning systems.

Multiple Emergency Planning Zones:

This functionality was introduced in the earlier versions of LIFESim to allow for different warning initiation times for different emergency planning zones. Recent improvements now provide for the possibility of using different warning systems and mobilization curves in each zone. This functionality is specifically useful for long reaches that can span multiple counties or states.

Future Work

Work has begun in collaboration with the USACE HEC to improve the user-friendliness of LIFESim so that a wider group of users can apply the full model. In addition, work has commenced to develop a Simplified version of LIFESim that can be applied with less effort than the full version. The USACE is particularly interested in using this version for their periodic assessments and portfolio risk assessments. In addition, there are various improvements, such as the addition of a rescue simulation component and work with sociologists to develop improved guidance for characterizing how people respond to warnings and the effectiveness of mobilization, that are expected to improve the capabilities of LIFESim in the future.

Conclusion

The increasing use of risk assessment to support dam and levee safety assessment and decision-making has made the need for life-loss simulation more urgent. LIFESim has been developed in response to this need. It provides a practical means of developing life-loss estimates using readily-available data with the consideration of a range of factors that have been demonstrated to affect the extent of life loss in natural and dam break floods. The scale-independent approach to life-loss estimation is a break-through that overcomes a severe limitation of previous approaches. The on-going work is expected to both improve the accessibility of LIFESim as a practical tool and the quality of estimates obtained from using it. LIFESim also provides an opportunity for dam owners to collaborate with emergency managers and first responders to explore ways to improve the effectiveness of emergency preparedness plans and to conduct more realistic simulation exercises.

Acknowledgements

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References

Aboelata, M. 2005. ‘Conceptualization and Development of a Dam Break Life-Loss Estimation Model.’ Ph.D. Dissertation, Utah State University, Logan, UT.

Aboelata, M., and D. S. Bowles. 2006. ‘Evacuation and Life-Loss Estimation Model for Natural and Dam Break Floods.’ Proceedings of the U.S. Society on Dam Conference, San Antonio, TX.

Aboelata, M., D.S. Bowles and A. Chen. 2004a. ‘Transportation model for evacuation in estimating dam failure life loss.’ Proceedings of the Australian National Committee on Large Dams Conference, Melbourne, Victoria, Australia.

Aboelata, M., D.S. Bowles and D.M. McClelland. 2003. ‘Life-loss Estimation for Floods including Dam Failure.’ GIS Model for Estimating Dam Failure Life Loss. In Y.Y. Haimes and D.A. Moser, (Eds.), American Society of Civil Engineers.

Aboelata, M., D.S. Bowles and D.M. McClelland. 2004b. ‘A Model for Estimating Dam Failure Life Loss.’ ANCOLD Bulletin 127:43-62. August.

BOSS. 1999. ‘BOSS DAMBRK: User’s Manual.’ BOSS International, Madison, Wisconsin.

Bowles, D.S. 2007. ‘Life Loss Estimation for RAMCAP’, Appendix D in Conventional Dams and Navigation Locks, Sector-Specific Guidance (SSG), Risk Analysis and Management for Critical Asset Protection (RAMCAP) Phase III for Dams, Locks and Levees. Prepared for the Department of Homeland Security by ASME Innovative Technologies Institute, LLC. August.

Chauhan, S.S., and D.S. Bowles. 2001. ‘Incorporating Uncertainty into Dam Safety Risk Assessment.’ In Proceedings of Risk Analysis in Dam Safety, Third International Conference on Dam Safety Evaluation, Goa, India. December.

FEMA (Federal Emergency Management Agency). 2003. ‘HAZUS®MH flood technical manual.’ Department of Homeland Security, Emergency Preparedness and Response Directorate, FEMA, Mitigation Division, Washington, D.C.

Graham, W.J. 1999. ‘A Procedure for Estimating Loss of Life Caused by Dam Failure.’ Report No. DSO-99-06, Dam Safety Office, U.S. Bureau of Reclamation, Denver, CO.

Greenshield, B.D. 1935. ‘A Study of Traffic Capacity.’ Highway Research Board Proceedings, Vol. 14, pp. 448-477.

HEC. 2002. ‘HEC-RAS, River analysis system user’s manual.’ Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California.

McClelland, D.M., and D.S. Bowles. 2000. ‘Estimating Life Loss for Dam Safety and Risk Assessment: Lessons from Case Histories.’ In Proceedings of the 2000 Annual USCOLD Conference, U.S. Society on Dams (formerly U.S. Committee on Large Dams), Denver, CO.

McClelland, D.M., and D.S. Bowles. 2002. 'Estimating Life Loss for Dam Safety Risk Assessment - a Review and New Approach.' Institute for Water Resources, U.S. Army Corps of Engineers, Alexandria, VA.

Rogers, G.O., and J.H. Sorensen. 1988. 'Diffusion of emergency warning.' The Environmental Professional, 10: 281-294.

Stedge, G., M. Landry, and M. Aboelata. 2006. 'Estimating Loss of Life from Hurricane-Related Flooding in the Greater New Orleans Area: Loss-of-Life Modeling Report', Final Report, Abt Associates Inc., Suite 600, 4800 Montgomery Lane, Bethesda, MD 20814-5341.

TRB. 2000. 'Highway Capacity Manual.' Transportation Research Board, National Research Council, Washington, D.C.

USACE, 2007. 'Performance Evaluation of the New Orleans and South East Louisiana Hurricane Protection System'. Final Report of the Interagency Performance Taskforce (IPET). Vol. VII-The Consequences.