LIFE SAFETY HAZARD INDICATOR

Background

The Life Safety Hazard Indicator (LSHI) is a value that represents the relative potential loss of life for a specific flood scenario. The LSHI is a screening level metric that can be used to inform the prioritization process for investments based on life safety. The indicator is computed based on factors that are generally understood to have the most significant, large scale impacts on potential loss of life from flooding: population at risk, warning time, and inundation depth.

The LSHI is considered relative, rather than absolute, because it should not be considered or communicated as an actual estimate of potential loss of life if a proposed flood damage reduction project is not implemented. It is recognized that attempting to estimate an absolute loss of life for a specific flood event requires a detailed understanding of many items related to the population at risk (PAR) and flood characteristics, including the PAR demographics, the timing of the warning (hour, day of week, season), the content of the warning message the PAR receives, how the PAR receives the warning, the responsible agencies' emergency action planning, the evacuation potential for the PAR, the sheltering potential in various available structures, the flood characteristics (timing, extents, depths, velocities, rate-of-rise, temperature, etc), and many other items. For that reason, the values computed using the approach described herein should not be presented or used as an estimate or prediction of loss of life for a specific flood event. Rather, the simplifying assumptions presented herein present a reliable, comparable, relative value for prioritization of investments based on potential loss of life.

The LSHI was developed to help inform the USACE flood risk management (FRM) budgeting process. Traditionally, FRM budgeting was based primarily on economic information, specifically a benefit-cost ratio. An “FRM Risk Index” was developed in recent year to assist with inclusion of life safety considerations along with economics in the budgeting process. The “FRM Risk Index” was computed based on factors generally known to influence loss of life, including population at risk, warning time, depth, and velocity. However, the computation approach was not supported by research or physics, and the resulting index was not intuitive and therefore limited in its ability to support decision making. Also, the “FRM Risk Index” was not a true representation of risk in that it only considers consequences and not the likelihood of occurrence of those consequences. The LSHI replaces the “FRM Risk Index” and was developed based on existing life loss estimation research. It is based on the same theory that existing approaches within the USACE Dam and Levee Safety programs and the Office of Homeland Security Critical Infrastructure Protection and Resiliency program use for estimating flood related loss of life.

The FRM budgeting process is divided into two general categories: funding for feasibility studies and funding for construction projects. For projects in construction the queue, the flood scenario represented by the LSHI is the design level elevation for the selected alternative. The design level is the elevation up to which the project would alleviate flood impacts if it performs as designed. For projects in the study phase, an alternative and related design elevation has not been identified, so the LSHI represents the maximum potential hazard that would typically be considered in the project formulation phase. Currently, the water elevation for the 0.002 annual chance event (500-yr) is considered appropriate for projects in the study phase. For the given flood scenario, the LSHI computation factors in 1) the population at risk (PAR) in the potential impact area, 2) the amount of warning time available to that PAR from when a flood warning is issued to actual inundation, and 3) the average depth of flooding across the impacted area.

Methodology

The Life Safety Hazard Indicator computation is described in the equation below. There are three parts to the equation: the Population at Risk (PAR) of flooding, the percentage of the PAR that does not evacuate prior to arrival of inundation, and the fatality rate applied to the PAR still remaining when the water arrives.

$$LSHI = PAR * \underbrace{\left[1 - \left[\frac{0.98}{1 + e^{4.825 - 0.0425(WarningTime)}}\right]\right]}_{\text{\% of people not evacuated}} * \underbrace{\Phi\left(\frac{\ln(Depth * 0.3048) - 5.2}{2}\right)}_{\text{Fatality Rate}}$$

Below is a description of each of the inputs used in the computation of the LSHI:

Population at Risk (PAR)

The *PAR* represents the number of people residing within the projected inundated area. The PAR is estimated by determining how many people would be located at or below the elevation for the flood scenario.

Warning Time (Mobilization Percentage)

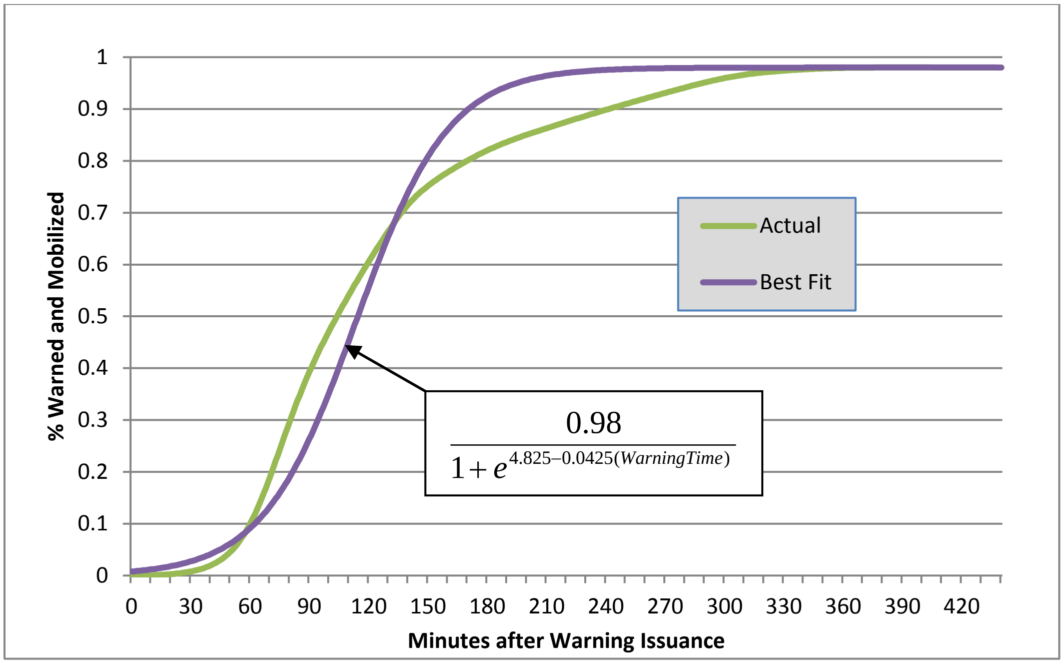
The *warning time* is used to compute a factor that represents the percentage of original PAR that will not mobilize prior to being inundated. “Mobilize” is when a person leaves the location where they received the warning and starts moving toward potential safety. The mobilization percentage equation is based on quantitative research that focused on warning dissemination relationships performed by Rogers and Sorensen (1988) and mobilization relationships performed by Duclos et al. (1989). Warning time is in *minutes*.

Rogers and Sorensen’s research illustrates how the time of day and warning system type (Emergency broadcast system, reverse 911, sirens, etc) impact how quickly a warning spreads through a population at risk. The approach used to generate the percentage of people that will receive the warning over time for the LSHI is based on warning being issued at 2 pm in the afternoon and disseminated via the Emergency Alert System (EAS).

To represent the percentage of people that both receive a warning and mobilize, the warning dissemination relationship described above was combined with a generic mobilization relationship. This mobilization relationship represents the amount time that people at risk spend preparing to mobilize after they receive a warning. The mobililiztion relationship used for this approach is a standard mobilization relationship presented in the research performed by Duclos et al. The combined relationship represents the percentage of people that have received a warning and mobilized with time, where time 0 is the time when an evacuation order is issued.

Finally, the percentage of people that would mobilize was capped at 98% for this approach. That results in at least 2% of the PAR not mobilizing, which represents the very real understanding of mobilization theory where a small percentage of almost any PAR will not leave the area due to mistrust of authorities, desire to protect property, inability to leave in a timely fashion, and many other reasons.

A curve was fit to the combined warning and mobilization relationship to allow for a representative mathematical relationship to be included in the LSHI computation. The actual combined warning and mobilization relationship and the best-fit curve are shown in the figure below.



Depth (Fatality Rate)

Average depth is used to compute the average fatality rate that is applied to the population that remains in the impacted area. The fatality rate computation is based on research out of TU Delft (Jonkman, S.N., 2007) and is the same approach used in the Corps Levee Screening Tool (LST). Their research illustrates that life risk can generally be represented as a function of depth and that fatality rate follows a lognormal distribution of the depth. In the equation, *PHI* and *ln* illustrate that the fatality rate follows a lognormal distribution of the depth, with a mean of 5.2 and a variance of 2.

Limitations and Recommendations for Further Development

As indicated, the LSHI is a relative indicator of potential loss of life. It has been formulated to inform the process for prioritization of investments based on life safety considerations with minimal supporting data. It is important to understand that the indicator is a very coarse estimate, with many simplifications and assumptions built in. The resulting values should be used accordingly. The values that are computed should be considered as one piece of information in the prioritization of investments decision-making process, not the final answer. Decision-makers must be aware of the assumptions and limitations of the overall LSHI computation as well as the specific considerations of each computed value.

The LSHI should not be used in the planning process to identify the best flood risk management alternative based on loss of life. The methodology behind the indicator is not detailed enough to adequately differentiate between alternatives. The methodology and tools for evaluating and comparing flood risk management alternatives based on loss of life within the planning context (i.e. feasibility study) is under development at HEC (HEC-FIA and HEC-WAT/FRM). That methodology does not include the limitations and simplifying assumptions contained within the LSHI, which are identified below.

Limitations and Simplifying Assumptions

Simplifying assumptions of the LSHI compute include the following general items, as well as many other items not specifically called out herein:

1. *Velocity not considered:* Velocity is not considered in the LSHI compute for various reasons. Research has shown that velocity is an important consideration when estimating loss of life from

flooding in areas where the combination of depth and velocity is greater than the stability threshold for structures where people may be sheltered. These large velocity/depth combinations are generally located in areas near a breach of a dam or levee. Once beyond the breach zone, which is relatively close to the breached structure, the velocities quickly diminish and depth becomes the driving factor for estimating loss of life. Given that, an estimate of average velocity over the impacted area would not be useful for estimating loss of life as it is the relatively small, confined areas of high velocity (i.e. near a breach) that really impacts life loss. And while these locations could end up having a significant impact on the total life loss, they are not identifiable within the scope of the LSHI. Decision-makers should be aware of this issue, and understand that if the project being considered is for rehabilitation of a dam or levee, and there is a significant population located near the dam or levee, then the LSHI for that project is underestimated in the relative context of the portfolio.

2. *Time required to evacuate not considered:* A simplifying assumption within the LSHI is that everyone who receives a warning and mobilizes is safe. In reality, the PAR is not safe until it travels through the threatened environment and reaches a safe location (typically outside the inundated area). In the majority of historic flood incidents, loss of life does not occur during the evacuation process due to evacuees being overcome by flood waters (not including those that choose to unnecessarily travel into flood waters that exceed the stability threshold of their vehicle). In areas where the time required to travel to safe location is excessively large and the warning time is short, the potential for people to be overcome during the evacuation process is larger. In those situations, the LSHI is underestimated in the relative context of the larger portfolio.

3. *Characteristics of Warning System, Content and PAR not considered:* A simplifying assumption within the LSHI computation is that all PAR receives warning through the Emergency Alert System (EAS) and they all respond at the same rate. These assumptions mean that the PAR all receives the same message and responds consistently. In reality, the type of warning system can have a significant impact on how quickly the PAR receives a warning. For example, at 2 AM the emergency alert system is typically not very efficient because it relies on people watching TV and listening to the radio to be effective. If warning sirens and reverse 911 capabilities are available, the warning will spread much quicker through a PAR in the middle of the night. Also, it is generally understood that the content of the warning message has a significant impact on how quickly people will respond to an evacuation warning. Finally, the demographics of the PAR will impact how they respond to an evacuation order. These limitations and assumptions mean that the LSHI is more of a representation of the relative life loss potential caused by the flood characteristics (depths, speed of onset of inundation) than it is of the actual loss of life.

Consistency of Inputs

Currently, the guidance for estimating the inputs into the LSHI is limited. The guidance on how the PAR, average depth over the study area and warning time should be estimated is not clear and there are not standard tools available to help with developing those inputs. Obviously, if inputs cannot be provided with some basic level of consistency, then the ability to make decision in a relative nature is limited.

RECOMMENDATION: A web-based tool should be developed to allow for more consistent input and collection of required data for the LSHI. The tool would be accessible to Corps' planners, and would allow them to enter the required LSHI inputs by completing the following steps:

1. Digitize a polygon of the potential inundation area over a standard set of base maps (i.e. arial photography) or import one from readily accessible database (i.e. national levee database).
2. Enter the water surface elevation for the design event (construction phase) or 0.002 annual chance exceedence event (study phase)
3. Enter the average warning time for the design event (construction phase) or 0.002 ACE event (study phase)

After a polygon of the potential inundated area has been defined, then the LSHI tool would complete the following:

1. Intersect that polygon with the FEMA HAZUS database to generate PAR and potential economic damages.
2. Pull a digital elevation model from readily available sources (i.e. NLD) and project the user defined water surface elevation across that DEM to generate an inundation depth grid for the potential inundated area. The LSHI tool would then compute a weighted fatality rate across the inundated area following the approach used within the levee screening tool. That approach divides the inundated area into 10 consequence zones and computes the fatality rate and PAR for each of those zones.
3. Compute the percentage of the population that has not evacuated based on user defined warning time.
4. Compute the LSHI.

LSHI and Risk

The LSHI is not a complete representation of risk because it does not account for the likelihood of occurrence for the flood event in question. Risk is the combination of likelihood of occurrence and resulting consequences. The LSHI is the consequence portion of the risk equation. To use the LSHI in a true risk informed process, it must be combined with the likelihood of occurrence for the event it represents.

Risk is traditionally represented in terms of expected annual consequences. To compute expected annual consequence for an area, the complete range (from most frequent to most infrequent) of potential events must be evaluated. Risk would be calculated by multiplying each event by its resulting consequence and summing all those values. A simplification of the total risk evaluation could be computed by assuming the relationship between the frequency of an event and it's resulting consequence is linear. In that case, the annualized consequence could be computed by multiplying the maximum potential consequence from the most infrequent event by ½. Then, the risk reduced could be computed by multiplying the LSHI by its annual chance exceedence and remaining (residual) risk would be computed by subtracting the risk reduced from the total risk. This process is very similar to that contained within the USACE Levee Screening Tool and is considered appropriate for informing a risk-informed decision making process for prioritization of investments based on potential loss of life.

RECOMMENDATION: Transform LSHI to a Life Safety Risk Indicator (LSRI) using the simplifying assumptions described above.

Use of LSHI for Prioritizing Investments

The LSHI and LSRI are useful values for informing the prioritization of FRM construction and study investments. However, an important consideration is "how high does the LSHI/LSRI need to be to elevate a project or study in the prioritization of investments?" A similar process is currently being followed by the Dam and Levee Safety programs for prioritization of investments. In that processes, a screening level risk assessment (similar to the LSRI) is computed and then decision-makers use that to classify projects in general categories of life safety (Dam Safety Action Classification/Levee Safety Action Classification). The step to go from the simplified, screening level risk computation to a safety action classification involves a group of senior staff reviewing the screening level assessment and using their understanding of the evaluation and its limitations to characterize the true nature of the risk for a given project.

References:

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Jonkman, Sebastiaan Nicolaas. Loss of Life Estimation in Flood Risk Assessment Theory and Applications. Delft University. 18 June 2007.

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