ESTIMATING THE LIFE SAFETY BENEFITS ASSOCIATED WITH FLOOD WARNING SYSTEMS

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Abstract

Our ability to answer questions about the value of flood warning systems and the benefit they provide in reducing risk, in both damage and loss of life terms, is subjective at best. We struggle to quantify the value of flood warning systems regardless of the level of service provided, or the risk posed to the communities those systems are set up to serve.

We assume that a flood warning system will reduce the potential loss of life arising from flood. While that seems reasonable, that assumption is founded on yet other assumptions about warning effectiveness and the response and / or evacuation of the population at risk.

The U.S Army Corps of Engineers recently engaged social scientists to better understand the process of warning and mobilising communities that experience severe flooding. This improved understanding facilitates a better assessment of the benefits associated with implementation or upgrade of a flood warning system.

This paper summarises the research conducted by the U.S Army Corps of Engineers and discusses the potential to apply it alongside the recently released HEC-LifeSim model, to better understand communities’ risk from flooding. When combined with the Total Flood Warning System (TFWS) concept, the approach offers valuable insight into the loss of life benefits likely to accrue from actions aimed at improving elements of the TFWS for communities subject to severe flood risk.

Introduction

It is generally accepted that flood warning systems deliver benefits in terms of a reduction in both actual damages and the potential for loss of life during flood events. However, while we intuitively “know” that establishing and improving flood warning systems is beneficial to at-risk communities as well as to the wider community, we struggle to quantify those benefits. This is because of the scarcity of relevant, empirical data.

HEC-LifeSim, a dynamic simulation model developed by the U.S Army Corps of Engineers for estimating life loss from severe flooding (Fields, 2016), offers potential for much needed assistance in this area. Key to that potential is that HEC-LifeSim models the warning and mobilisation of the at-risk community, and predicts the spatial distribution of fatalities within buildings and along transport routes.

The authors have applied HEC-LifeSim to a number of areas downstream of major Australian dams, and used it for concept design of a flood warning system downstream from one of those dams. That work and associated learnings are discussed in this paper, along with the authors’ thinking on the application of HEC-LifeSim to quantify the (loss of life) benefits likely to accrue from implementing or improving elements of a TFWS for communities subject to severe flood risk.
The Total Flood Warning System

In 1995 the Australian Emergency Management Institute published a best-practice manual entitled ‘Flood Warning: an Australian Guide’ (AEMI, 1995). The manual was informed by a series of workshops attended by flood management specialists following the 1990 floods across eastern Australia. In describing practices for the design, implementation and operation of flood warning systems, the manual introduced the concept of the ‘Total Flood Warning System’ (TFWS). It also focussed attention on the need to integrate the many elements of effective warning, while promoting the need for the coordination and integration of inputs from involved agencies. The manual was revised and updated in 1999 and again in 2009.

An effective total flood warning system is made up of several building blocks that are appropriately developed and integrated. The blocks (derived from EMA, 2009) are presented in Table 1.

<table>
<thead>
<tr>
<th>Flood Warning System Building Blocks</th>
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<tbody>
<tr>
<td><strong>DATA COLLECTION &amp; COLLATION</strong></td>
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<tr>
<td>The instrumentation and systems that monitor and provide data for analysis and storage</td>
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<tr>
<td><strong>DETECTION &amp; PREDICTION (FORECASTING)</strong></td>
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<tr>
<td>Analyses looking forward and / or comparison against thresholds / triggers</td>
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<tr>
<td><strong>INTERPRETATION</strong></td>
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<td>An ability to answer the question “what does this mean - will I or others be flooded and to what depth”</td>
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<tr>
<td><strong>MESSAGE CONSTRUCTION</strong></td>
</tr>
<tr>
<td>Getting the words and messaging correct – pre-canned or on-the-fly or something in-between</td>
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<tr>
<td><strong>MESSAGE DISSEMINATION</strong></td>
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<tr>
<td>Communication and alerting – getting the message to those who need to be informed / alerted</td>
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<tr>
<td><strong>RESPONSE (AND RESPONSE PLANNING)</strong></td>
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<tr>
<td>Knowing and taking appropriate actions – aimed at preserving life and reducing damage</td>
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<tr>
<td><strong>AWARENESS (AND EDUCATION)</strong></td>
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<tr>
<td>The understanding part – priming the system and community for a beneficial outcome</td>
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<tr>
<td><strong>REVIEW</strong></td>
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<tr>
<td>Gathering the lessons learnt post-event, identifying system improvements and programming implementation</td>
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Table 1: TFWS elements or Building Blocks

The Issue

Implementation or upgrade of a flood warning system will, for a variety of reasons, involve a concentration on particular elements of the TFWS. The technical elements (e.g. the data collection network and forecast model) often receive more attention at the expense of the socially focussed elements (e.g. the processes of warning and alerting, instilling awareness of flood risk and appropriate responses). Reasons for this are varied but are considered by the authors to relate to a combination of visibility and measurability, rather than to a purely objective consideration of the benefits such improvements might deliver to the at-risk community. There are also gaps in our ability to measure or otherwise quantify such benefits. In contrast, a new rain or river gauge, more timely or greater volumes of data, a more accurate or timely forecast, etc can be seen and the “improvement” quantified, photographed and “held”.

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This “improved service through more gauges and more accurate forecast” approach gives comfort to the technically-minded and is a physical manifestation of the flood warning system. But is it in these areas where we should be investing? Our flood-related loss of life statistics, ever increasing flood damages estimates, and oft repeated complaints of inadequate flood warnings suggest that we should be looking with more frequency to the other TFWS elements.

In an ideal world, communities at risk from flooding would be serviced by flood warning systems where the various elements of the TFWS are appropriately developed (or boosted) to match each community’s requirements. However, the data to inform decisions about which elements of the TFWS should receive immediate (or prioritised) attention for (further) development is scarce.

A Possible Solution

Following application of HEC-LifeSim to a number of Australian catchments, the authors suggest that the model provides a means of considering the benefits, in terms of reduced life loss, of investing in the further development of each of the TFWS elements for communities at risk from severe flooding. In saying that, it is acknowledged that what is done to implement or improve a flood warning service often has implications across more than one TFWS element. It is therefore important that the assembled base data accurately characterises the community’s current and likely future traits, attributes and behaviours. In such cases, the model can provide guidance on which TFWS elements are likely to give the best return on investment.

Obviously, an agency’s and / or community’s capability to implement improvements and their willingness to invest as well as the availability of required resources (i.e. skilled personnel, funding, appropriate facilities and infrastructure) are crucial to the translation of model findings to on-the-ground actions. The authors are not suggesting that HEC-LifeSim provides the complete and only answer to investment decisions in relation to flood warning system implementation or upgrade. They do contend however, that using HEC-LifeSim represents a more objective approach than has hitherto been available.

An Introduction to HEC-LifeSim

HEC-LifeSim is a spatially distributed dynamic simulation model that can be used to estimate the loss of life from any flooding scenario. It was first developed by Utah State University to improve loss of life estimation for dam failure consequence assessments, by overcoming some of the limitations of empirical approaches (Aboelata et al. 2002, 2003, 2004). HEC-LifeSim is now developed and distributed by the U.S Army Corps of Engineers (Fields, 2016) as freeware: there are no licensing requirements. There are also no special hardware requirements. HEC-LifeSim is available for use by anyone with a computer, though familiarity with HEC-RAS, hydraulic modelling and flood consequence assessments will accelerate the learning and use processes.

HEC-LifeSim is comprised of four major modules: flooding conditions, warning and evacuation, loss of shelter, and loss of life. Inputs include time-series of flood depth and velocity, the study area topography, building and population at risk (PAR) distribution, characteristics of PAR warning and mobilisation, and the transport network. The model simulates the evacuation of the PAR from the flooded area in response to warnings, or their distribution to zones that are ‘safe’, ‘comprised’ or represent only a ‘chance’ of survival (Figure 1).
Modelled flooding conditions for use with HEC-LifeSim can be obtained from a range of commercially available software packages, including TUFLOW, MIKE 21/Flood and HEC-RAS. This component of life loss modelling is not discussed further in this paper.

![HEC-LifeSim approach to modelling life loss from severe flooding](image1)

Figure 1: HEC-LifeSim approach to modelling life loss from severe flooding (Bowles, 2007)

Warning and mobilisation characteristics are simulated with curves that describe, for a given time, the proportion of the PAR who have been warned and taken protective action (Figure 2). An interview guide by Sorensen and Mileti (2015) can be used to ascertain which of the warning delay, warning diffusion and protective action initiation curves in HEC-LifeSim are most applicable for the PAR of interest (Needham et al., 2016). The questionnaire covers the emergency plans that exist, the first public alert that would be issued, how warnings are disseminated to the PAR and general public, the level of PAR preparedness, and the personal characteristics of the people who could be flooded.

![The warning timeline, up to initiation of protective initiation](image2)

Figure 2: The warning timeline, up to initiation of protective initiation (Needham et al. 2016)

Evacuation-transportation in HEC-LifeSim is simulated using the GIS-based transport network, user inputs regarding the proportion of people who evacuate via foot or vehicle, and in-built models of pedestrian and vehicle speed (based on traffic density). Pedestrians and vehicles are both assumed to take the shortest travel time to shelter. Should the route to the safe destination become inundated while the PAR is evacuating, the PAR will re-route if possible. Otherwise, vehicles or pedestrians are assumed to be trapped.
For the PAR who have not mobilised, the assignment of loss of shelter categories in HEC-LifeSim is based on depth-velocity particular to the building type they are in. Where buildings are negligibly or partially damaged, the loss of shelter category is based on submergence status, which is a function of the building’s height and the depth of flooding. For the PAR in vehicles or escaping as pedestrians, the flood zone is based on user-defined stability criteria, or criteria recommended in Australian Rainfall and Runoff (Shand et. al., 2010).

The loss of life in each flood zone is estimated using the fatality rates shown in Figure 3. These fatality rates were derived from approximately 180 case studies of catastrophic floods (McClelland and Bowles, 2002). The fate of PAR can be tracked using HEC-LifeSim’s animation capabilities.

![Figure 3: Probability distributions for fatality rates for each flood zone (Fields, 2016)](image)

Uncertainty in the estimates of life loss can be assessed in HEC-LifeSim using Monte Carlo techniques. Parameter distributions can be defined for selected inputs to the warning and evacuation, loss of shelter and loss of life modules. This capability allows the user to analyse the characteristics of a flooding scenario that have the greatest impact on loss of life estimates.

**Case Study**

The following case study is presented to illustrate the application of HEC-LifeSim and more particularly, how the results can inform TFWS development.

As part of a portfolio risk assessment, dam break modelling and consequence assessments were undertaken for a large Australian dam with a very seasonal and itinerant downstream population. An outcome from the risk assessment was quantitative estimates of the potential loss of life for a range of flood and dam failure scenarios. The potential loss of life estimates are sensitive to whether flood / dam break warning for the PAR is assumed to be “adequate”. In turn, that depends on when the event is likely to be detected, the procedures used to warn and mobilise those at risk, and the
characteristics of the inundation extent and local traffic networks.

A HEC-LifeSim model was developed in order to simulate warning and evacuation of the downstream population (i.e. the PAR) in the event of a severe flood. The warning and mobilisation elements were informed by the Sorensen and Mileti questionnaire (Sorensen and Mileti, 2015). An aim of the work was to gain a better understanding of how warning time influences potential loss of life and the ability of an early warning system to reduce life safety risks posed by the dam.

Model inputs included:
- Time series of gridded depths and velocities for the flood events extracted from the hydraulic model;
- A structure inventory including the distribution of those at risk;
- Emergency planning zones (i.e. areas with similar warning characteristics); and
- The road network (imported from Open Street Map) and the location of safe destinations.

Timings associated with the identification of a flood event and the warning and evacuation mobilisation processes were sampled from distributions estimated from the Sorensen and Mileti questionnaire (Sorensen and Mileti, 2015). While the questionnaire considered existing emergency and public alerting plans and processes (including how warnings are disseminated to those at risk and more generally, the characteristics of the PAR and the level of flood preparedness within the community), the sampling accommodated the variation in times that are likely in identifying the development of a flood and in constructing and disseminating an appropriate message to those at risk.

The HEC-LifeSim model was run with inputs from questionnaire responses reflecting the current no TFWS situation, for both day and night time conditions. The latter was incorporated through the use of different warning time diffusion distribution curves (refer to Figure 2). The model was then rerun with adjusted questionnaire responses to reflect various improvements to each of the TFWS elements. Each of these improvements was expanded out so that the scope of each was clearly documented. This included any underlying assumptions, as well as where responsibility for implementation and operation would reside.

In broad terms, the improvements considered were:
- The availability of rain and river data - was there a benefit in installing additional gauges or telemetry or in obtaining data from other locations?
- The timeliness of available rain and river data - were data collection, collation and presentation tasks timely and data available when and where needed?
- Forecast lead time - was the forecast adequate, what if it was available earlier?
- Knowledge of the consequences of flooding - were flood maps and flood intelligence available?
- Message construction - were forecasts and consequences shared with the at-risk populations in appropriate language?
- Message dissemination - can messages be disseminated quicker, better?
- Response planning and response - was there a flood response or other plan?
- Education and awareness - what flood preparedness and awareness measures were in place or could be implemented? and
- Review - was this a part of BAU with a feedback / improvement loop?

It was noted that the technical (i.e. the data collection, detection and forecasting) elements of the flood warning system were by and large reasonably well developed. It was further noted that with the availability of recently completed flood mapping, most of the technically based information required to inform the flood warning system was available.
In adjusting the Sorensen and Mileti questionnaire for an improved TFWS, it was assumed that there is a portion of the PAR who will not take any action, despite being warned (Gissing (2015) and Keys (2015)). While this portion changes with increased awareness of flood risk it is never reduced to zero: a rate approaching 90% would be considered exceptional.

Examination of results allowed conclusions to be drawn about the extent to which those at risk were likely to be caught by floodwaters, either because they failed to receive or act on a warning, or were caught on the road network as they evacuated. As might be expected, results indicated that a combination of early warning (i.e. the quicker the threat is detected the sooner the alerting, warning and response processes can begin) and high mobilisation rates (i.e. a timely response – knowing what to do and where to go) would result in a reduction in life loss during a major flood.

Improvements to the flood warning system therefore aimed to:
• Maximise warning lead time by reducing the time from threat detection to warning receipt, and by reducing the time it takes for a warning to be issued, received and acted on;
• Expand the reach of warnings through use of a variety of dissemination media;
• Make best use of available flood intelligence;
• Establish mechanisms and develop products to increase awareness of flood risk and appropriate response actions; and
• Develop and share community evacuation plans.

While not done as part of the above work, the model could have been used to evaluate proposed emergency evacuation routes and plans. As HEC-LifeSim tracks the movement of individuals via the road network, it provides a representation of population redistribution which in turn can provide useful insight to effective evacuation routes and destinations. Insights are aided by the animations produced by HEC-LifeSim (Fields, 2016). The animations are a powerful visual communications tool and greatly assist understanding of the interactions occurring.

Closing Comments

This paper has introduced HEC-LifeSim and demonstrated its application to estimate the benefits likely to accrue from improving various TFWS elements for communities at risk from flooding downstream from a large Australian dam. It also touched on the use of HEC-LifeSim to evaluate emergency evacuation routes and plans.

It is suggested that HEC-LifeSim could be used more generally to assist determination of the benefits associated with development or improvement of flood warning systems for communities at risk from severe flooding, particularly where loss of life is a credible outcome. A particular advantage is that the benefits of developing particular elements of the TFWS, either individually or as a package, can be determined without bias towards either the technical (e.g. data and forecasting) or social (e.g. awareness and behaviours) aspects. Further, as HEC-LifeSim tracks the movement of individuals via the road network and thereby provides a representation of population redistribution, it can provide useful insight to effective evacuation routes and destinations, an important part of the TFWS response element. The animations produced aid an understanding of risk and other factors involved in the evacuation process.

HEC-LifeSim is a valuable tool that can be used to facilitate the identification of flood warning system configurations that will meet community needs while delivering a best return on investment.
References


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