A TECHNICAL GUIDELINE FOR THE USE OF THE SES TIMELINE EVACUATION MODEL IN FLOOD EVACUATION PLANNING.

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Abstract

The NSW SES Timeline Evacuation Model ('the model') has been the de facto standard for evacuation calculations in NSW since it was first developed for evacuation planning in the Hawkesbury Nepean Valley more than a decade ago.

While the mathematics and logic behind the model calculations are relatively straightforward, there are a number of key considerations that can make its application highly complex. Notably, how to determine time that is available for evacuation, how to determine the model parameters such as the evacuation route capacity and evacuation trigger level, the implications of convergence of evacuation traffic from multiple centres and determining the consequences of a failed vehicular evacuation.

The NSW SES has recognised the need for the model to be more widely used and consistently applied in the planning of evacuation of existing communities and in the assessment of new development.

To this end it commissioned Molino Stewart to prepare a technical guideline that explains the model and provides step by step instructions on its use. Additionally, a simple Excel based tool has been developed to undertake the model calculations for a simple single evacuation route development. The guideline makes extensive use of graphics to clearly explain relevant concepts and draws heavily upon case studies where the model has been applied. Each case study has been chosen to represent a different set of challenges and considerations in the application of the model.

The Guideline provides a broad overview of the timeline evacuation model and its limitations for those who need to understand it for planning and approvals as well as detailed guidance on it use for those for those who need to plan or evaluate evacuation strategies for existing or proposed development.

Background

The NSW SES is the lead combat lead agency for floods (including coastal inundation), storms and tsunami. Under the *State Emergency Service Act, 1989* it is able to issue orders for mandatory evacuations.

Over the past 20 years the NSW SES has taken a more analytical approach to planning for such events which has included assessing the likely triggers for evacuations, their potential scale and the time required to effect them.

Failure to evacuate in a timely manner can lead to individuals, or even whole communities, being isolated without essential services and without access to hospital grade medical services. Those that are attempting to evacuate may become stranded or overwhelmed by flood waters along their evacuation route. In some situations, should floodwaters continue to rise, isolated land can be completely overwhelmed by floodwaters and lives will be placed directly at risk. In each case, the NSW SES is faced with the prospect of conducting rescue operations which themselves can carry risk to lives.

To assist the NSW SES in its emergency planning role, including evacuation planning, two guidelines have been produced to help those working in floodplain management provide the information which the NSW SES needs. These are the *Flood Risk Management Guideline – SES Requirements for the FRM Process* (DECC, 2007a) and *Flood Risk Management Guideline – Flood Emergency Response Classification of Communities* (DECC, 2007b)

In addition, the NSW SES has developed a Flood Evacuation Timeline Model (Opper et al, 2009) to quantify flood evacuation needs for a locality or region and to assist the NSW SES in its flood evacuation planning. Increasingly, the model has also been used to assess the evacuation implications of proposed developments.

The NSW SES has developed The Timeline Evacuation Model as an empirical means of consistently estimating the ability of people to safely evacuate by motor vehicle. It takes into account the time people take to accept a warning, act upon the warning and travel along an evacuation route which may face delays due to incidents along the route. It then compares this estimated “Time Required” with the estimated “Time Available”. The Time Available is derived from information about warning times, flood travel times and flood rates of rise.

The NSW SES decided that it should produce a guideline which sets out the NSW SES recommended methods for calculating both the Time Required and the Time Available and provides guidance on what values should be assumed in the model and where data can be obtained to estimate the other values used in the model. Molino Stewart was commissioned to produce the Guideline and an accompanying Excel based tool for applying the model.

This paper is only able to provide a broad overview of the Timeline Evacuation Model, The Guideline and Tool. The Guideline and its technical appendices should be referred to for details about assumptions and limitations and how to use the Tool.

The Timeline Evacuation Model

Overview

The Timeline Evacuation Model was born out of the 1997 Hawkesbury-Nepean Floodplain Management Strategy, where the NSW SES applied conventional time line project management to the flood evacuation problem. It became apparent that this approach provided a clear and concise method for examining the evacuation process. Since that time, the approach has been refined into a model that can be easily applied to different developments. The model has been used widely within NSW by both the NSW SES and consultants in evacuation planning, with the scale of the model ranging from small sub divisions to valley wide evacuations with up to 70,000 people. The model has also been applied to the planning of major events such as music festivals.

The primary goal of The Model is to compare the time required for evacuation with the time available for evacuation. This can be represented by the equation:

Surplus Time = Time Available – Time Required

or:

ST=TA-TR

Where the Time Available exceeds the Time Required there can be greater confidence that a community can evacuate safely by motor vehicle. Where the Time Required exceeds the Time Available it is unlikely that everyone will be able to evacuate safely by motor vehicle in all floods.

The Guideline also recognises that evacuation of a development may not necessarily occur in isolation as other nearby developments may also have to evacuate at the same time. The model also makes provision for estimating how converging evacuation traffic may impact on the ability of developments to evacuate simultaneously.

However, it must be recognised that evacuation in a real flood may not occur as set out in The Model. Flood behaviour, weather conditions, road and traffic conditions and incidents could all vary from the assumed values in the model. Furthermore, warning systems can fail and people may not respond appropriately or in a timely manner to the warnings. For this reason the consequences of failure of vehicular evacuation also need to be taken into account. This Guideline sets out how to consider personal safety in the event of vehicular evacuation failure.

If the limitations of the model and consequences of evacuation failure are taken into account, it is appropriate to use The Model results to inform decision making within the merits based framework as set out in the NSW Floodplain Development Manual.

Steps in Warning and Evacuation

The Model breaks down the events and procedures that will occur during a flood in a chronological order (hence it is referred to as the Timeline Evacuation Model). Typically, the following sequence of events will occur prior to, and during a flood:

1. The Bureau of Meteorology (BoM) will identify the potential for high rainfall, and inform the NSW SES (this may occur days before the expected time of a

weather event) and will provide the NSW SES with a 'heads up'. There can be very high uncertainty in weather model results at this time.

2. The BoM may issue a flood watch or a severe weather warning with the possibility of flash flooding based on available data. This might include radar and satellite data, rainfall data and/or stream gauging data as well as output from weather, rainfall and flood forecasting models. This will provide an idea of the potential scale of the event. The data and models available vary with location and event size and type. There is generally a high level of uncertainty about the final location and actual gauge level of flooding, however, the BoM says that statistically about 75% of all Flood watches are followed by a flood (somewhere in the general footprint of the Flood Watch area). Despite the uncertainty inherent in a Flood Watch, it gives the NSW SES an opportunity to consider the potential consequences and timing of flood impacts and even to pre-position resources before bad weather precludes this.

3. As an event progresses more data will become available and the BoM will be able to provide forecasts with greater confidence. If the probability and consequences of flooding are sufficiently high, the NSW SES will make a decision to prepare to evacuate the likely flood affected areas and mobilise emergency service personnel accordingly. (Typically the NSW SES requires about six hours for such mobilisation). It may broadcast an evacuation warning to the community at some time during this phase to prepare it for the possibility of evacuation.

4. Once more rain has fallen, the Bureau will issue updated forecasts and, in catchments where it can, it will provide predicted flood heights and timings with increasing certainty.

5. The NSW SES will decide to evacuate an area based on the certainty of the forecasts, the time available for evacuation and the consequences of evacuation failure.

6. Once the decision has been made to evacuate, the NSW SES will broadcast an evacuation order using a number of methods as well as distribute the order by other means. If resources are available, this may include door knocking those areas that need to evacuate.

7. Once residential or business premises receive the evacuation order, the occupants may take some time to decide whether they will evacuate or not. During this time they typically seek confirmation of the evacuation order through other means including official broadcasts or their community networks. The Model includes a Warning Acceptance Factor (WAF) to account for the time taken for this activity.

8. Once the occupants have accepted the direction to evacuate, they will take some time to prepare to evacuate. (i.e. pack belongings, lift items above expected flood levels in a building etc.). The Model includes a Warning Lag Factor (WLF) to account for the time taken for this activity.

9. Once the occupants have begun to evacuate, there is a limit to the capacity of the evacuation route, so it will take time to clear all of the traffic. The time that vehicles are travelling is referred to as the Travel Time (TT) in The Model. This is not the time taken for each vehicle to travel along the route but the total time during which the route is being used by all evacuating vehicles.

10. There may be delays during evacuation caused by such things as fallen trees or power lines, inundated roads or vehicle accidents or break downs. The Model accounts for this by including a Traffic Safety Factor (TSF).

11. The evacuation route will be cut off at some point by flood waters. After this point, any traffic which has failed to evacuate will have occupants that will need to be rescued.

A simplified evacuation timeline which shows both the case where the time required exceeds the time available and where the time available exceeds the time required is shown diagrammatically in Figure 1.

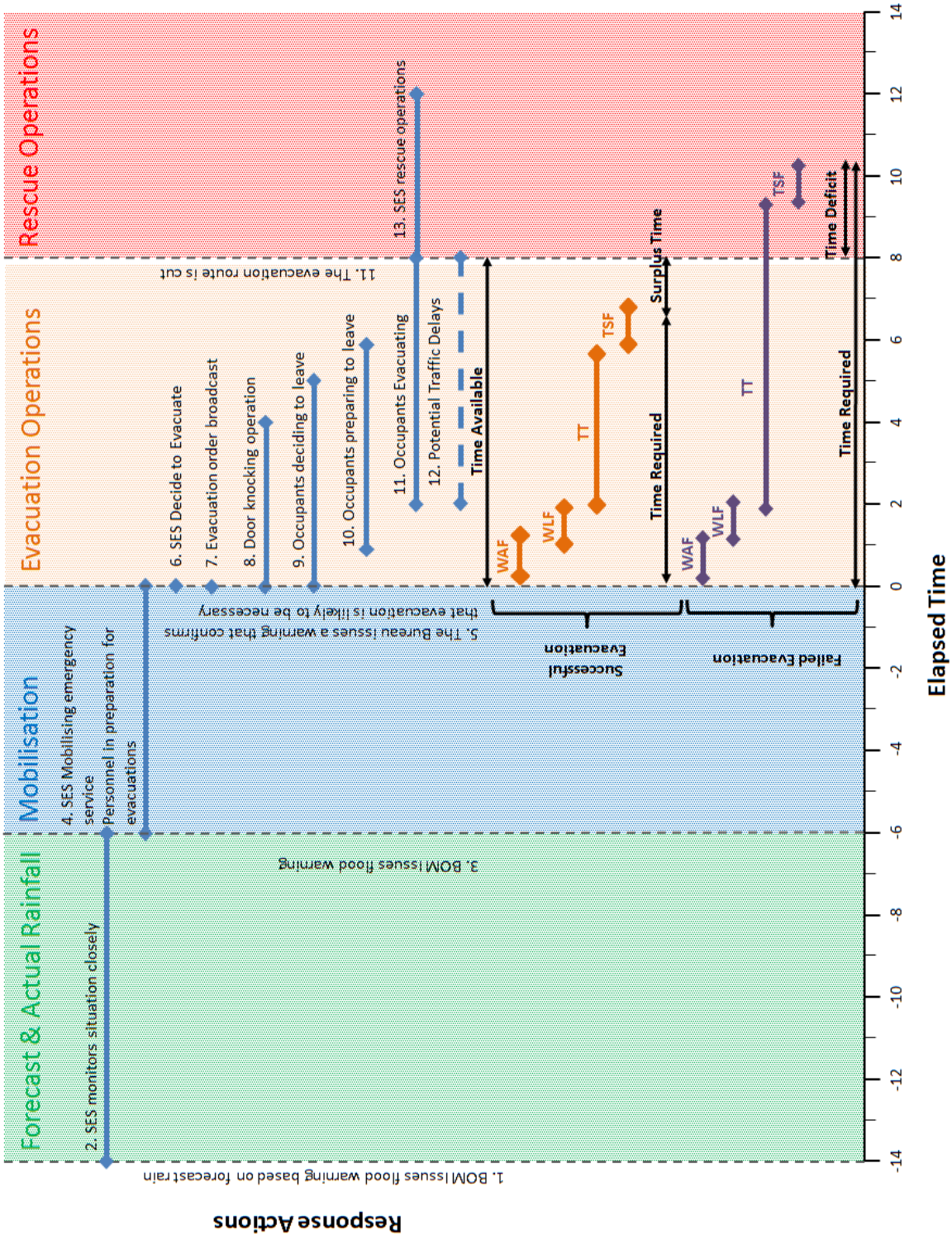

Figure 1: Simple Evacuation Timeline

Estimating the time required

The time required can be described by the equation

TR = WAF + WLF + TT + TSF

Where:

Warning Acceptance Factor (WAF) accounts for the delay between receiving an evacuation warning and acting upon it. The NSW SES recommends a value of one hour.

Warning Lag Factor (WLF) is an allowance for the time taken by occupants to prepare for evacuation. The NSW SES recommends a value of one hour.

Travel Time (TT) is defined as the number of hours taken for all of the evacuation vehicles to pass a point given the road capacity. The NSW SES recommends an assumed road capacity of 600 vehicles per hour per lane. Therefore if an evacuation generates 1,200 vehicles and the evacuation route has one lane, then the travel time is two hours.

Traffic Safety Factor (TSF) is added to the travel time to account for any delays that occur along the evacuation route. This includes potential for incidents such as vehicle accidents or breakdowns, fallen trees or power lines or water across the road. The NSW SES has developed a table of traffic safety factors, where the safety factor is proportional to the travel time, ranging from one to three and a half hours.

The time needed to disseminate an evacuation order also needs to be considered. Generally, the NSW SES will broadcast the order by several means but will also initiate doorknocking of the target premises. The model assumes that the evacuation order is not received at a property until it is doorknocked and that at any one time there will be properties at different stages of the evacuation sequence. This is illustrated in Figure 2 which shows the doorknocking and evacuation sequence for a series of properties and the sum total of their evacuation time. This shows how the time required for doorknocking does not directly contribute to the overall time required to evacuate because it is taking place simultaneously while people that have been doorknocked are commencing the evacuation process.

However, this is only true if the number of door knocking teams available is equal to the number that would produce enough traffic to keep the evacuation route at full capacity. Should the number of door knocking teams available be less than this optimal number, then the travel time must be modified to account for this. If more door knockers are provided than the optimal number then the rate of traffic generation will exceed the road capacity and traffic queues will form until no more premises evacuate.

Given that the NSW SES provides most of the recommended values in the Time Required equation, the Guideline's focus on this part of The Model is providing guidance on how to estimate the Travel Time which can be described by the equation:

Travel Time (TT) = Total Vehicles (TV)/Route Capacity (RC)

or;

TT= TV / RC

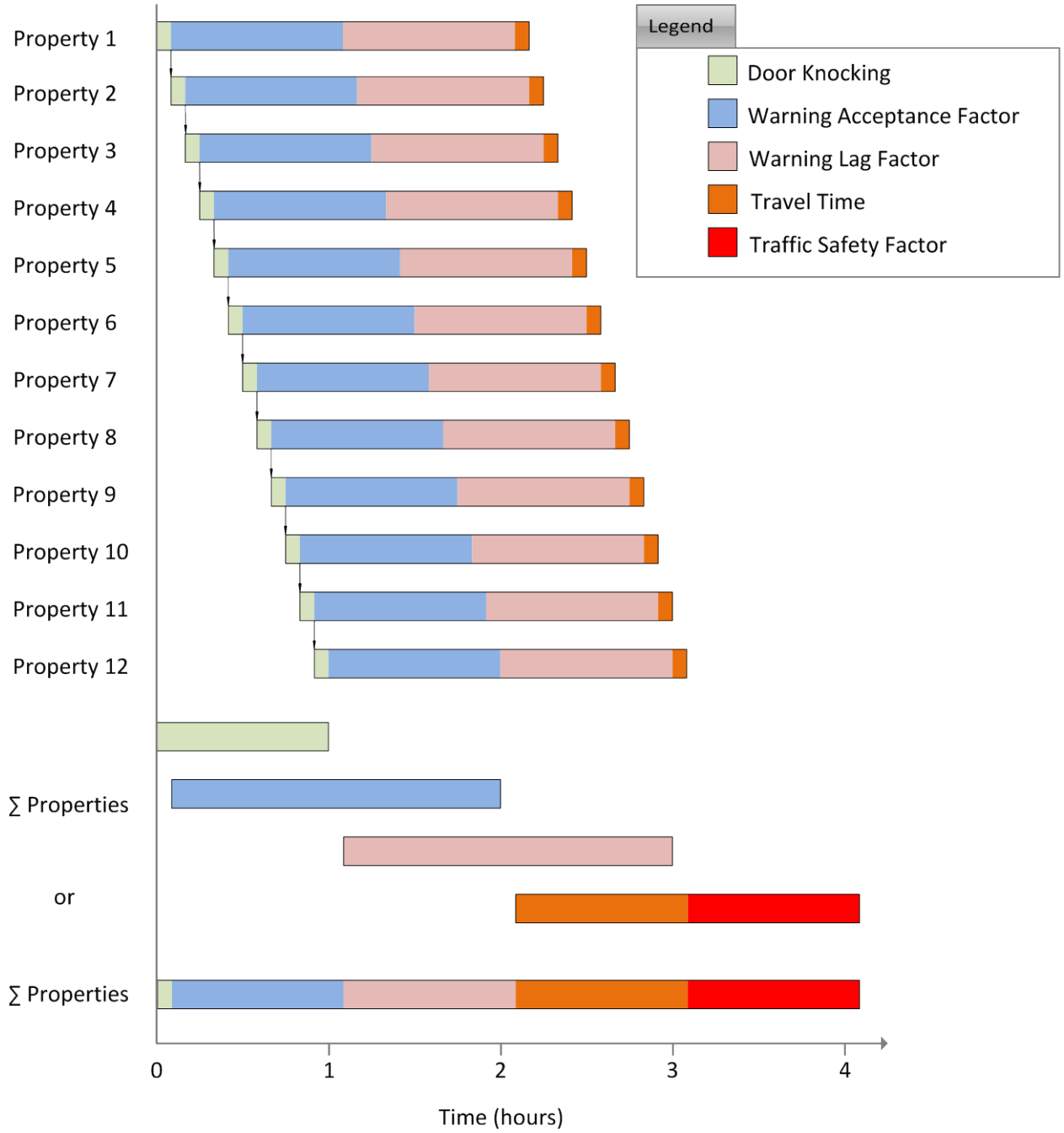

Figure 2: Evacuation Sequencing

The Guideline provides a great deal of detail on potential sources of information for estimating the total number of vehicles taking into account:

- Whether it is existing or proposed development
- The mix of residential, business and other developments
- The time of day or time of year evacuation is likely to occur, if that is relevant
- Whether properties beyond the extent of flooding need to be evacuated because of isolation issues

Similarly, guidance is provided for estimating the number of lanes available for evacuation taking into account:

- Local road networks and origin of vehicles
- Sequencing of flooding and evacuation
- Bottlenecks along the evacuation route
- The potential for convergence of traffic from different directions

Estimating the Time Available

The time available is usually the time from when an Evacuation Order is issued by the NSW SES to when the lowest point on the evacuation route is cut by floodwaters. The ability to estimate this time for use in The Timeline will be very dependent on the quality of available flood data, and the type of warning products which the Bureau of Meteorology (BoM) is able to provide.

From an evacuation planning point of view there are four categories into which BoM warning may fall:

- BoM publishes (e.g. in the NSW State Flood Sub-plan) the minimum amount of warning time which is likely to be available during a flood (e.g. seven hours for Penrith for Nepean River flooding) and then gives a quantified warning for particular gauge locations during a flood including the time which a particular level is expected to be reached at that location.
- BoM cannot commit to minimum warning times but will nevertheless publish quantified flood warnings (e.g. X metres at Y bridge) and may give a broad timing of expected flood levels.
- BoM can only provide warnings of minor, moderate or major flooding along a river with no specific heights and often no specific locations
- BoM does not provide specific warnings. In many catchments BoM may not have sufficient data, modelling or time to predict specific flood warning, in these situations the BoM may, subject to availability of timely information, issue a severe weather warning which mentions the potential for flash flooding in a particular region.

It is also possible for flooding to occur with no warning from the BoM. This is particularly the case with flash flooding.

Any flood can be represented by a hydrograph at specified points along a river. A hydrograph plots how the water level goes up and down. Because The Model is interested in the minimum time which is likely to be available, the PMF hydrograph

should be used for these steps. This does not mean that The Model is only estimating the time available in a PMF. Modelled design floods and even records of actual floods only represent one possible rate of rise for a flood to reach a particular peak. Floods with peaks smaller than a PMF could rise at rates approaching that of a PMF, particularly in the range in which evacuation needs to take place which is often well below the flood peak.

Figure 3 shows a theoretical PMF hydrograph for a location along a river where the BoM is able to provide a quantified flood forecast with an indication of the time when the level will be reached. In this particular case the warning time to the evacuation route being cut is the BoM forecast time.

Figure 4 shows a hydrograph where the BoM is unable to provide an indicative time to levels being reached. In this case the warning time will be the time that the river takes to go from a trigger level to the level at which the evacuation is cut. In this case the warning time will be the height difference between the trigger level and the evacuation route being cut, divided by the rate of rise in a PMF between those two levels.

When determining the Time Available, consideration also needs to be given to the relative position of where the warning is provided for compared to the location where the road will be cut. For example, if the area of interest is significantly upstream or downstream of the warning location (usually a flood gauge) then the flood travel time needs to be considered. This is illustrated in Figure 5 and Figure 6.

Figure 5 shows the situation where the gauge location is upstream of the evacuation route low point. In this case the warning time (either BoM forecast or time to rise) needs to be added to the time it will take for these flood waters to progress downstream and cut the evacuation route. In this case the Time Available is equal to the warning time plus the flood travel time.

Figure 6 shows the opposite situation. Here the evacuation route is upstream of the gauge and the Time Available is equal to the warning time minus the flood travel time.

Other Considerations

In keeping with the principles of the NSW Floodplain Development Manual, the results of The Model calculations must be considered within a risk framework and merits based decisions need to made as to the appropriateness or otherwise of modelled evacuation arrangements for existing and proposed developments.

The following highlight some of the issues which need to be considered beyond the results provided by The Model.

Traffic Convergence: While each community, development or precinct must be evaluated individually to determine whether full evacuation is possible, it must be recognised that the evacuation traffic from several locations may be directed to the same road and therefore the potential for traffic convergence to affect completion of the evacuation must be considered.

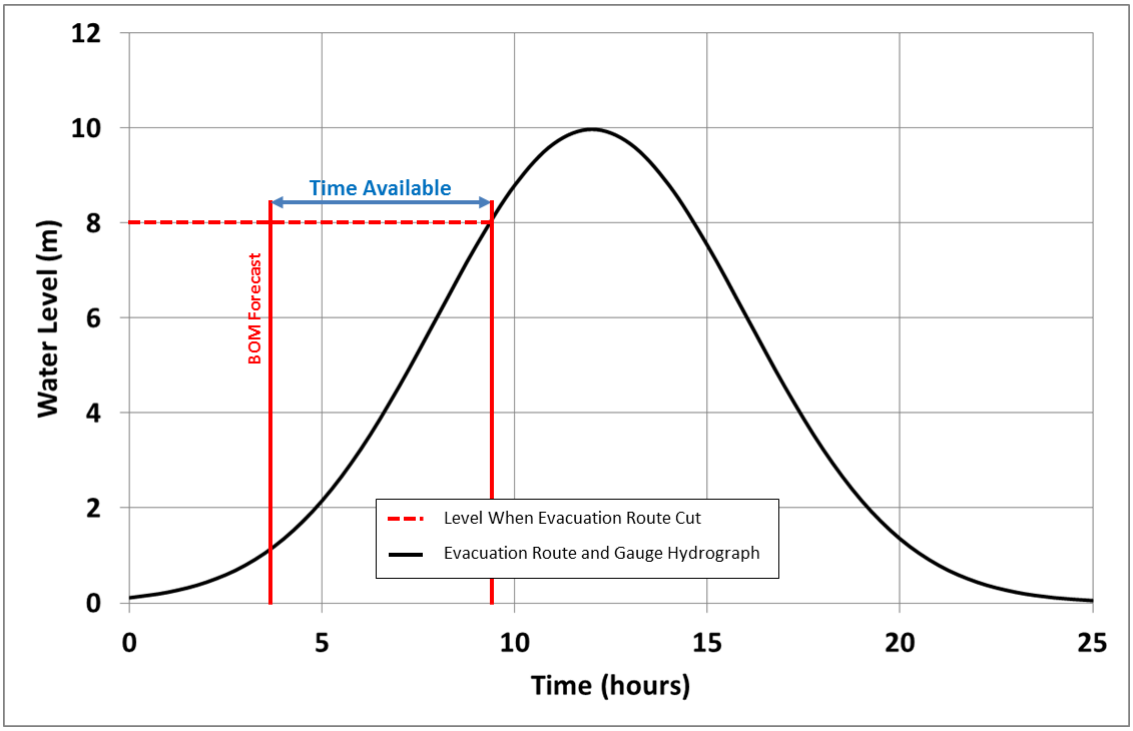

Figure 3 Hydrograph where the BOM forecast time equals the Time Available

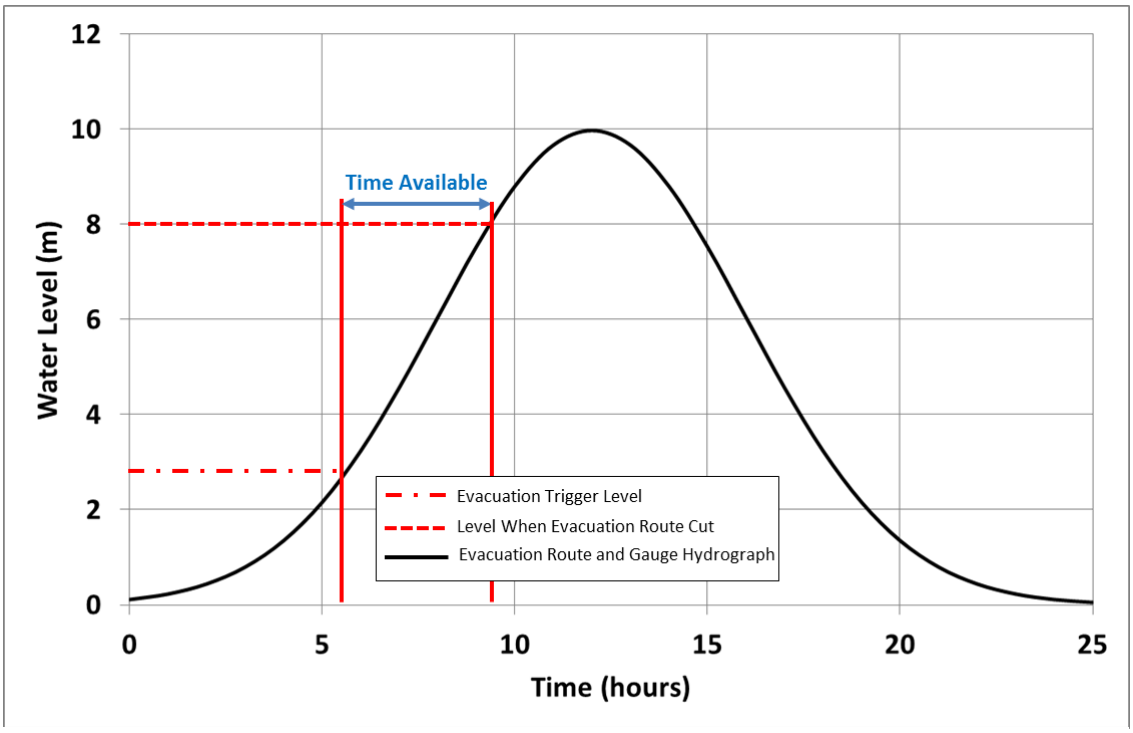

Figure 4 Hydrograph where the time to rise from trigger level to route cut level equals the Time Available

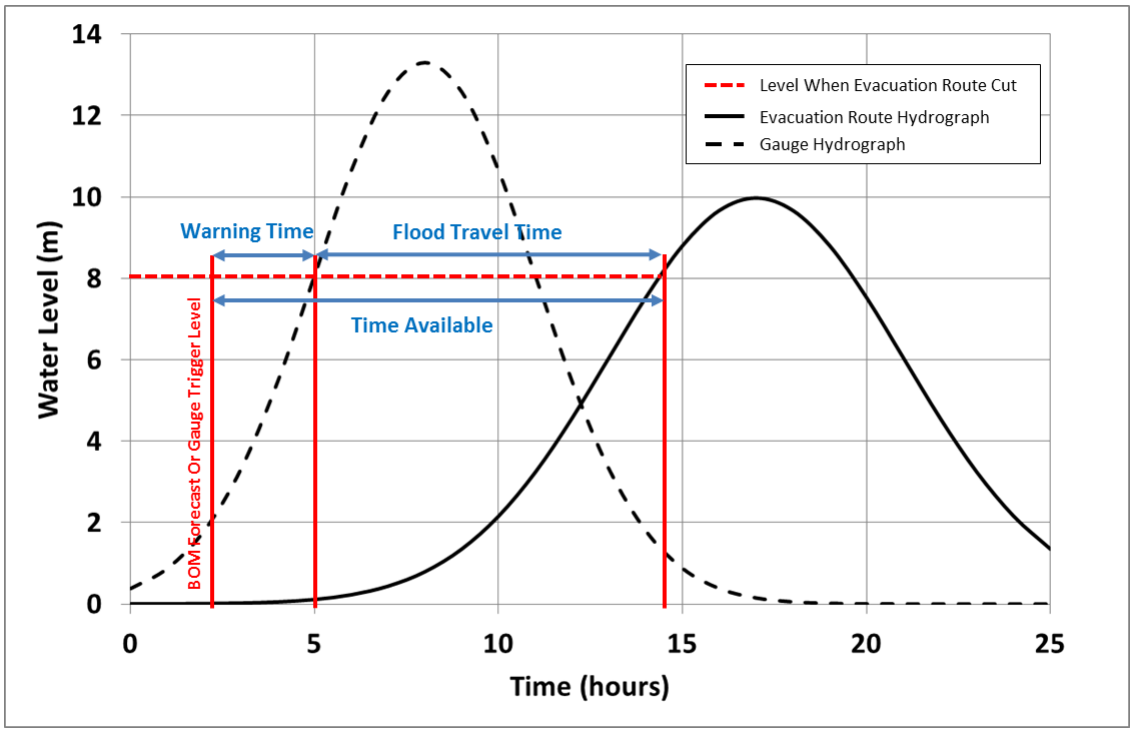

Figure 5 Hydrograph where the warning time plus the flood travel time equals the total Time Available

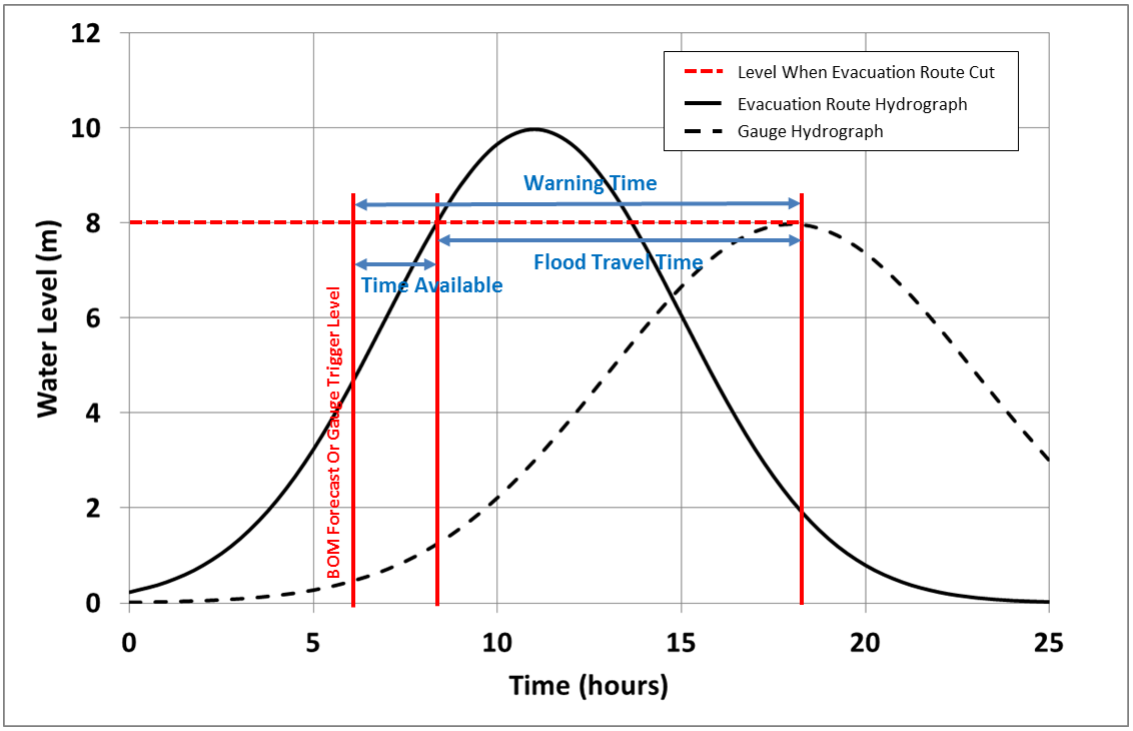

Figure 6 Hydrograph where the warning time minus the flood travel time equals the total Time Available

Local Flooding: The analysis in The Model regarding the timing of flooding cutting evacuation routes is focussed on the routes being cut by the flooding which is triggering evacuation. However, the routes may be cut by flooding from another source (eg: localised flash flooding or oceanic flooding, occurring at the same time).

Safety Margins: Any surplus time calculated through the timeline evacuation modelling can be considered to be a safety margin should any of the model assumptions prove to be non-conservative. This is a particularly important consideration where new development will share an evacuation route with an existing development. In this situation the new development will be taking up some, or all, of the safety margin which the existing development currently has available.

Consequences of Evacuation Failure: There are many reasons why vehicular evacuation may fail. It therefore must be acknowledged that some, or all, of the evacuees will be unable to evacuate by motor vehicle. The probability and consequences of such a failure must come into consideration when determining the appropriateness of a new development or reviewing the adequacy of emergency plans.

Sensitivity of Variables: Default values for many of the variables used in The Model have been determined by the NSW SES (shown in Appendix C). It is expected that any application of The Model will utilise these default values, except where it can be clearly justified to use alternative values. Other variables will need to be derived from available flood modelling, census data, council records and development details. There may need to be assumptions made in selecting values from this data for use in The Model. The sensitivity of The Model to these assumptions should be tested to ensure that any conclusions drawn from using the model are robust.

With regard to the consequences of evacuation failure, the Guideline makes reference to the Floodplain Risk Management Guideline: Flood Emergency Response Planning Classification of Communities (DECC) (2007b). This classification determines whether those who fail to evacuate by car:

- have safe walking access to a flood free area
- would be isolated and/or overwhelmed by rising floodwaters

While a safe walking access may be available to flood free land, the distance involved and the time taken to walk that distance may mean that it is not a practical method of evacuation for most people. The Guideline and Tool provide a means of estimating this.

The Tool

The tool itself is a password protected Excel spreadsheet consisting of eight worksheets.

1. *Instructions* – this is a set of simple instructions on use of the tool. It is not a substitute for reading and following the detailed guideline document.

2. *SES Recommended Values* – this lists the variables for which the NSW SES has recommended values and includes those values. It allows those values to be varied but requires the justification to be entered into the spreadsheet for later reporting.

3. *Input data Development A* – this is where data specific to a development is entered. This worksheet also picks up relevant data from the NSW SES

Recommended Values worksheet and combines all of this data to calculate an estimated surplus time which is presented at the bottom of the worksheet.

4. *Input data Development B* – this is the same as the preceding worksheet except that it enables data to be entered for another development, precinct or town which needs to be evacuated from the same flood as Development A.

5. *Convergence Calculations* – this worksheet uses data from preceding worksheets, along with inputted values on the relative timing of evacuations of Development A and Development B, to estimate the extent to which the two traffic streams will converge and the length and duration of any resultant traffic queues and whether with convergence there remains surplus time.

6. *Pedestrian Evacuation A* – this worksheet uses data on the distance to flood free land and the rate of rise of floodwaters to determine whether walking ahead of rising floodwaters is a practical alternative means of evacuation should vehicular evacuation not occur.

7. *Pedestrian Evacuation B* – as for the preceding worksheet but for a second area which needs to be evacuated.

8. *Report* – this summarises all of the relevant input data and calculation results from the preceding spreadsheets and presents them in an A4 summary report. It includes a space to insert a map and description of the evacuation routes for developments A and B. An example report sheet is included as Appendix A.

Conclusions

The Timeline Evacuation Model is a tool for analysing the practicality and likely effectiveness of flood evacuation from new and existing developments.

As a model it is a representation of what might happen in an actual flood and cannot be relied upon as a definitive forecast of how an evacuation will occur in reality. For this reason it is important when using The Model to:

- undertake sensitivity analyses around the assumed values in the model
- be aware of circumstances which may prevent evacuation occurring as modelled
- understand the consequence of failed vehicular evacuation

With these things taken into account, it is appropriate to then use The Model results to inform decision making within the merit based framework as set out in the NSW Floodplain Development Manual.

The NSW SES Evacuation Capacity Assessment Guideline and Tool are still in final draft stage and may be subject to some minor changes before the project is finalised. Councils, developers and consultants wishing to use the tool should not rely on the summary provided in this paper as it is based on the draft completed at the end of March 2013. They should seek the final guideline and tool soon to be made available by the NSW SES.

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State Emergency Service Act 1989 (NSW).

Appendix A

Sample Report from Timeline Evacuation Model Tool

SES Timeline Evacuation Model. Report Generated From Standard Tool Version 4.0 (26/05/2013)

Date:	
Development A:	E.g. Floodside Development A
Development B:	E.g. Floodside Development B
Calculation ID:	E.g. ILP_V3_R2
Calculations By:	E.g John Smith, XY Consulting
Notes:	E.g. Configuration with 2 egress points

Input Data	**Development A**	**Data Source**	**Development B**	**Data Source**
Number of Residential Vehicles	3337.2	E.g. Indicative Layout Plan (ILP) Version 3 Revision 2	1545	E.g. Existing Setup
Number of Commercial Vehicles	1000	E.g. ILP Version 3 Revision 2	100	E.g. ILP Version 3 Revision 2
Evacuation Route Capacity (lanes):	1	E.g. Google Earth, critical location is Flood Street	2	E.g. Google Earth, critical location is Flood Street
BOM Forecast Time	8	E.g. State Flood Plan	8	E.g. State Flood Plan
Additional Time	1	E.g. Allowance for rising road access or remote gauge	0	E.g. Allowance for rising road access or remote gauge
Flood Emergency Response Categorisation	Area with Rising Road Access	E.g. Floodplain Risk Management Study	Low Flood Island	E.g. Floodplain Risk Management Study

Variables	**Value**	**Justification**
Lane Capacity (Vehicles per Lane)	600	SES Default
Warning Acceptance Factor (hours)	1	SES Default
Warning Lag Factor (hours)	1	SES Default
Queue Length per car (m)	6	SES Default
Pedestrian Evacuation Walking Speed (km/hr)	2	SES Default

Evacuation Results	**Development A**	**Development B**
Travel Time (hours)	7.2	1.4
Traffic Safety Factor (hours)	2.0	1.0
Evacuation Time Required (hours)	11.2	4.4
Evacuation Time Available (hours)	9.0	8.0
Surplus Time (hours)	**-2.2**	**3.6**
Total Number of Vehicles	4337	1645
Vehicles Not Evacuated	**1337**	**0**
Door Knocking Teams Required	23.7	55.2

Paste Evacuation Route Figure Development A

Traffic Convergence	**RELEVANT**
Time of Overlapping Evacuation (hours)	2.4
Total Delayed Evacuations (vehicles)	**1423**
Total Queue Length (m)	4
Queued Development	B
Net Surplus Time for Queued Development	**2.4**

Pedestrian Evacuation	**Development A**	**Development B**
Longest Distance for Pedestrian Evacuation (m)	5000	5000
Time Taken to Walk to Flood Free Land	2.5	2.5
Time Taken for Water to Rise to Peak	2.0	1.3
Net Time for Pedestrians to Evacuate	**-0.5**	**-1.2**

Evacuation Route Development A	**Evacuation Route Development B**
E.g. Egress and 1st street	
E.g. Left onto 2nd street	

Paste Evacuation Route Figure Development B