The Application of Timelines to Evacuation Planning

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Abstract

In 1997 the NSW SES became involved in the Hawkesbury-Nepean Floodplain Management Strategy, a project aimed at addressing the flood risk for up to 80,000 people living on the floodplain downstream of Warragamba Dam to the west of Sydney. A critical aspect of the studies that underpinned the development of the strategy was an understanding of the timing and dynamics of large scale flood evacuation operations. To assist the author is his own understanding of that problem, experimentation was undertaken to apply conventional time line project management to map out the elements of an evacuation operation. It was immediately obvious that the time line was an excellent tool for communicating the problem to others. The time line analysis became a central element of major project work used to demonstrate the need for a new multi-million dollar high level flood evacuation route for Windsor in the Hawkesbury-Nepean Valley. Since 1997 the methodology has matured into a functional tool that can be used to assess the evacuation requirements of existing communities or the impact of new urban development proposals. This paper explains the basic principles of evacuation time line analysis, looks at the key inputs that are required to enable the analysis to be undertaken, and also discusses the limitations of the methodology.

1. Introduction

Since 1998 the NSW State Government has been in the process of dealing with the 1997 report of the Hawkesbury-Nepean Flood Management Advisory Committee. That report entitled Achieving a Hawkesbury-Nepean Floodplain Management Strategy (HNFMAC, 1997) and its many recommendations was adopted in full by the Government in 1997.

Working under the overall project management of the then Department of Land and Water Conservation, now The Department of Infrastructure Planning and Natural Resources (DIPNR) the SES is the lead agency for the implementation of the emergency management recommendations of the Strategy. A significant number of the recommendations related to the need to review the existing flood emergency management arrangements including: reviewing the Hawkesbury-Nepean Flood Emergency State Plan (HNFESP), upgrading flood warning systems, implementing a flood awareness program and upgrading the regional road network to cater for the flood evacuation traffic.

Directly related to the Hawkesbury-Nepean flood planning, the NSW SES has been developing a graphical method for the analysis of flood warning and evacuation scenarios. The method is an adaptation of basic time line management or critical path diagrams. The resulting diagram is a time line of emergency response for flood evacuation. This method has the advantage of showing how critical the relationship is between flood prediction, evacuation decisions, emergency service response and community actions and the passage of time in a flood. Although discussed in the context of evacuation, the time line concept could be adapted to many other operational issues.

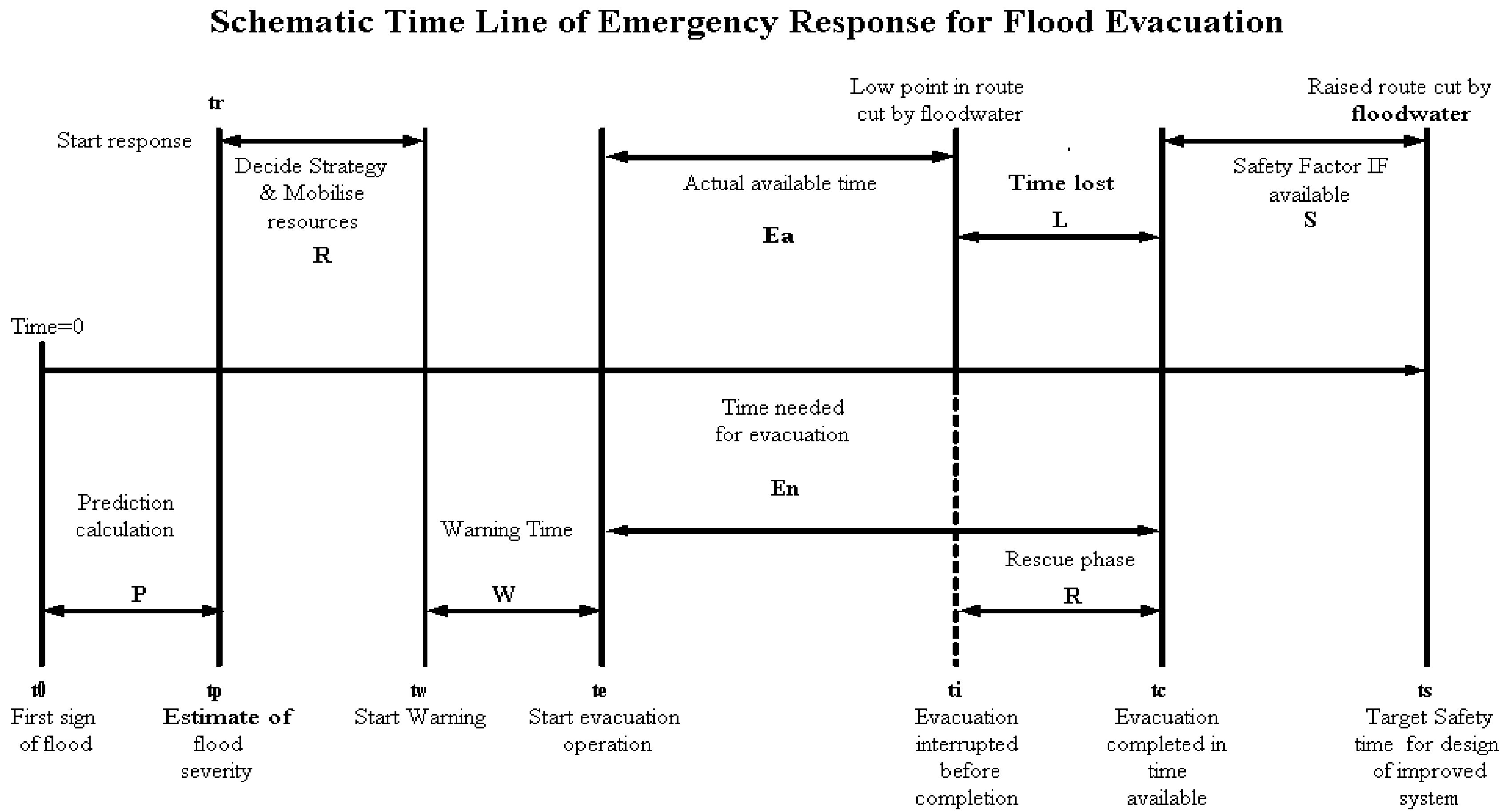
2. Evacuation Time Line Analysis

The method of preparing an evacuation time line as follows. A horizontal line represents how much time is expected to be available in a flood with the amount of time available will be influenced by the rate of river rise. Marked off along the line are the points of occurrence of known events e.g. when a flood prediction will be given, when roads will be closed by flooding. Next, in sequential order along the line, the duration of each decision or action is marked off, **including safety factors**. The resulting time-line can then be used to show participants in a flood planning or response activity what has to be done, when it has to be started, and approximately how long it might take during the flood scenario analysed.

Figure 1 on the following page is a schematic diagram of an evacuation time line. The various elements of the time line are discussed in the section following Figure 1. When considering the time line shown the following points should be noted:

- The time line cannot start until the point in time when the Bureau of Meteorology (BoM) has some indication that a severe flood is developing. This point is nominally called time zero.
- The closure by flooding of the last useable evacuation route marks the end of the available evacuation time.
- If the total time required for all actions and safety factors exceeds the available time between time zero and route closure, there is a time deficit that must be corrected if the risk is to be managed.
- Upgrading the evacuation route will be the most reliable option. The route must either be made to last longer i.e shift the end-point of the time line to the right or the number of available lanes must be increased i.e move more vehicles in the same time period.
- Each time element can be shown as a discrete sequential element, this is called a **sequential time line** but it is recognised that in practice, some overlapping would occur, although this cannot be easily quantified. If elements of the time line are treated as being concurrent events by overlapping them, this is called a **concurrent time line**. The time occupied by each element has a direct impact on the time available for all other elements.
- Warning and traffic movement are the elements most likely to take place concurrently in a real flood event. There is a critical interrelationship between these two elements and this is discussed in more detail in subsequent sections.

Figure 1- Time line of Emergency Response for Flood Evacuation



Notes: S will be a negative value (safety Factor < 0) when ti occurs earlier than tc. S will be zero when all available time needed (En) is used. Only when ti occurs after tc does a Safety Factor begin to accrue. The magnitude of S has to be determined by reference to the capacity to cope with uncertainty and interruptions. The time elements are not drawn to scale in this diagram but should be for proper analysis.

The main elements of the time-line are:

2.1.1. Flood Prediction

– Represented by **P** in Figure 1. Factors than can influence **P** include:

a) Physical characteristics of the catchment

b) Data collection: methods, hardware, transmission

c) Flood modelling capability: data, software, history

d) Human resources: staff availability, experience and activation time

e) Prediction dissemination: communication, recipients contact procedures (eg SES)

f) Weather forecasting capability: severe weather advice, Flood Alerts, forecast reliability.

2.1.2. Response Initiation (Decision Making & Mobilisation)

Represented by **R** in Figure 1.

The time needed to initiate emergency response operations is a complex mix of organisational, communications, procedural and legislative factors. Factors that could influence **R** include:

a) Data availability in relation to the problem and the physical environment

b) Emergency response planning

c) Training of personnel

d) Communications systems and methods

e) Exercising activation and delivery of specific response procedures.

2.1.3. Warning Delivery

Represented by **W** in Figure 1.

Warning preparation and delivery could be expected to represent an element where significant time is required. The SES has found that a reliable warning method is door-to-door delivery by emergency service personnel. In floods many other methods of warning may used including radio, TV, sirens, telephones or other technological options however the time frame for these methods cannot be realistically assessed.

2.1.4. Evacuation Operations

The key elements of the evacuation operation are represented by the terms **Ea**, **En**, **L** and **S** in Figure 1.

The evacuation operations resulting from a major flood will be the most complex and time consuming aspect of the overall flood response operation.

En represents the total time required to complete a full evacuation of all people in their vehicles, a time that will only be available assuming there are no unexpected impediments (see **L**) to using all of the calculated (theoretical) time.

L represents the time lost (which has to be subtracted from En) due to flood closure or failure of evacuation routes or transport systems before completion.

Ea represents the actual available and within which evacuation must either be completed by adapting the process to the time constraints. The portion of evacuation not completed by time **tc** will result in the need to begin a rescue operation. Rescue is failed evacuation!

The interval **S** represents the safety factor or time buffer that may be available if there is a reserve of additional time available to deal with interruption or uncertainty. The safety factor will only exist if the chance of the interval **L** occurring can be reduced to near zero (there is no likely impediment to using all of the total necessary evacuation time).

Evacuation arrangements must maximise opportunities for a timely response. Factors influencing the response will include:

a) Transport routes: their capacity and resilience to damage, alternative routes (redundancy), vehicle weight and size limits, vulnerability to local flood effects (storms, creeks), vulnerability to mainstream flood effects,

b) Transport methods; private vehicles, public transport, special vehicles (eg for medical contingencies),

c) Traffic control and coordination: priority setting of traffic lights, manual control of intersections, good route signage,

d) Management of the removal of personal effects, pets, and livestock, from property before/during evacuation,

e) Destination facilities for safe storage of personal effects, pets, and livestock,

f) Marshalling and processing facilities for evacuees, and

g) Accident handling arrangements on evacuation routes.

2.2. Estimating the Duration of Time Line Elements

When determining the nominal time zero or estimating the duration of each element of the time-line, the purpose of the analysis has to be considered. A decision has to be made about how conservative the time estimates will be. When modelling the impact of a new urban development for example, the time estimates must be suitably conservative and reflect high standards of public safety. In contrast, when trying to prepare an implementable emergency response plan for an existing urban environment where time availability is restricted and cannot be extended due to physical, social or financial constraints, the time line may have to use less conservative time estimates. This discussion on estimating element duration does not deal with the subject of safety factors which is dealt with separately in a subsequent section.

2.2.1. Flood Prediction Element

The decision to evacuate an entire community should ideally only be made if the need is indicated by a clear prediction of the severity of a coming flood. If this is not possible there are likely to be many pre-emptive evacuations that will, only with the benefit of hindsight, turn out to have been unnecessary. The evacuations will be costly to the community and that cost must be factored into a balanced flood risk management assessment.

A serious problem for emergency managers is that if there is any doubt about how high the water will rise during a developing flood, residents have to be evacuated well before they are cut off. Most urban areas, especially those built on flood plains in recent years, are built in such a way that dwelling floor levels are higher than the network of access roads. In floods residents will be cut off from flood free high ground before their homes are flooded and then if water continues to rise, the homes may be completely inundated.

After receiving a flood prediction it will take a finite time to undertake such a large scale evacuation including: making the evacuation decision, getting emergency services into position to assist; warning residents; and moving evacuation traffic along evacuation routes. The time required can be estimated during flood emergency planning (SES, 2000) and the closure of existing evacuation routes by flooding is the main constraint on available time.

The lead-time requirements for large-scale evacuation operations place great demand on the Bureau of Meteorology (BoM) to provide very early predictions of flood severity. It is in the nature of weather and flood predictions that the earlier a prediction is required, the greater will be the degree of uncertainty attached to that prediction.

The BoM flood prediction modelling relies on the input of rainfall data for the river system catchment. This is known as rainfall/runoff modelling. The rainfall data can be either actual measurements from rainfall gauges or estimated rainfall data from a computer weather system model. This latter type of data is known by the BoM as **Quantitative Precipitation Forecast (QPF)**. For any catchment there will a flood model performance point beyond which the BoM can only provide additional prediction lead-time by relying on QPF. In this paper this point is called the **QPF Limit**.

At Annex A is a diagram showing how an estimate of the QPF limit can be found for the Penrith and Windsor areas in the Hawkesbury-Nepean valley. It indicates a minimum 9 hour no-QPF prediction lead time for 14mAHD at Windsor and a minimum 7 hour no-QPF prediction lead time for the 1% AEP level at Penrith.

In some cases, because of the size of the population in relation to physical constraints such as roads, if the evacuation decision is not made until predictions are above the QPF Limit, there will not be enough time to carry out the evacuation before the evacuation routes are flooded. The period of time between the QPF Limit and the end of the evacuation window is referred to in this paper as being above the QPF Limit. To provide the lead-time required under these conditions, the BoM flood height prediction will have to be based on QPF i.e. forecast rainfall. This is a highly uncertain environment for requiring serious decision making and massive community response.

This means that there must be an opportunity for either of the following responses to a flood:

1. Ideally all residents can leave their home without external assistance and with minimal warning lead time and could even prepare and leave without any risk of being trapped as flood water advances into the area or,
2. If a managed evacuation operation is required, it can be safely undertaken when the prediction of severe flooding is based on actual rainfall i.e. the prediction can safely be made no earlier than when a flood reaches the height corresponding to the QPF limit.

2.2.2. Decision Making and Mobilisation Element

Having received a flood prediction from the BoM, the SES must assess the likely impact of the coming flood and **decide** on a course of action using the appropriate flood plan as a guide. It will then be necessary to **mobilise** the resources needed and to communicate the planned intentions to the community (**warning**). The first two of these three elements are an area where a precise formula cannot be used to calculate the time requirements and safety factors and the experience of the SES in managing floods must be applied to the problem.

The amount of time that needs to be allocated for decision making and mobilisation of resources depends in part on the degree of certainty attached to the flood prediction and on the scale of the operation that is anticipated. If the first advice from the BoM about the possibility of severe flooding is well below the QPF Limit and relies heavily on forecast rainfall, the decision making process will be much more difficult and could take longer.

If the scale of the operation is expected to be very large, resources will have to be moved into the area from some distance away, possibly even interstate, and this will take many hours. It can be seen that these two processes, decision making and mobilisation, have contradictory requirements. The confidence level of decision making benefits from a delay and mobilisation benefits from an earlier decision.

The SES recommends that for the purpose of time line planning in the context of either future urban growth assessment or the design of improvements to an existing urban setting, a period of no less than 6 hours should be allowed for the combined processes of decision making and mobilisation of resources. In cases where the environment cannot be modified for an existing at risk population, it may be necessary to try and determine mobilisation time by conducting physical scenario-based exercises.

2.2.3. Warning Element

The warning time is calculated using an estimate of how long it would take the specified number of two-person teams to physically knock on the door of each house. This is the likely to be the slowest but also the most certain warning method and it is possible to estimate the time it will take. The SES has tested door knocking in the field (900 homes at McGraths Hill in 2001 and 1,300 homes at Windsor in 2003) and the results indicate the need to allow a time of 5 minutes per team per door. As an example, 120 houses and one team = (120 x 5)/1 = 600 minutes, 120 houses and two teams = (120 x 5)/2 = 300 minutes.

In a real flood situation the SES will also use other warning methods including TV, radio, and telephone. The time frame for warning delivery by these methods is likely to be shorter than for door knocking but there is no way of assessing beforehand how long it will take for the community to receive the warning. In any case, warning very large numbers of people in a short time frame may not achieve an overall reduction in the evacuation time frame because of limits to evacuation traffic flow (see A Limit to Warning Speed and traffic flow below).

It is not considered safe to rely on theoretical calculations that suggest very short warning time frames even when door knocking is being modelled. For example, it might be found that with 10 teams of doorknockers a population of 250 dwellings could be warned in 2 hours. This suggests that if 30 teams were applied to the task, the warning will be completed in under one hour but this result ignores the organisational issues that must be carried out by the door knocking teams and human behaviour(discussed below).

It is considered necessary to account for the time lag between the delivery of a warning and when the occupants would be ready to depart from the scene. People need time to organise themselves and prepare for evacuation. This is referred to as the **Warning Lag Factor (WLF)** and a minimum period of 1 hour is allocated to the WLF in the analysis. The WLF **is not** an optional safety factor, it is a discrete and essential element of the overall evacuation time line.

As warning is best treated as an element that takes place concurrently with traffic movement – a concurrent time line, the WLF is added to the start of the concurrent traffic movement element. This because traffic begins only after the WLF has ended. The WLF also needs to be added to the end of the concurrent warning period to account for last warned dwelling. This means that the period WLF plus traffic movement cannot end earlier than the period warning plus WLF.

2.2.4. Traffic Flow Element

Traffic flow has a number of aspects to consider and is not a simple as calculating the number of vehicles past a point on a road. The lane capacity, number of lanes available, potential for closure by flooding (by local storms or main river), the potential for temporary closure due to car crash or trees/power lines falling onto a road are all critical considerations.

Before discussing evacuation route traffic capacity calculations the issue of localised storm water flooding of both internal streets and external roads used for evacuation must be considered. Without proper design to a suitable storm water flow standard, there is risk of roads being closed by local storms before the main river flood even reaches them (HNFMAC, 1997). Local storm closures could delay evacuation for so long that available evacuation time will run out before everybody has reached safety. During the implementation of the Hawkesbury-Nepean Flood Management Strategy(HNFMS, 2000) a design standard of 1:500AEP has been adopted for storm water or creek crossings on critical evacuation routes.

It is the flood durability and traffic capacity of evacuation routes that has the greatest impact on total available time. Planning values for traffic flow must be realistic for the expected conditions in a flood. The emergency planning for vehicle movement is based on an average flow rate of 600 vehicles/hour/lane(HNFMAC, 1997; HNFMS, 1998; HNFMS, 2000). This number is derived from a typical rural road design flow rate of 1200 vehicles/hour/lane, down-rated by a factor of two (1200/2=600) to account for the adverse driving conditions such as heavy rain, darkness and driver unfamiliarity that are likely to prevail (worst credible case planning).

2.2.4.1. Dual lane Outbound Traffic Flow

In some circumstances it may be possible to design the road system to cope with dual outbound lane traffic flow. There are three options for providing this:

- a conventional dual lane carriageway (two lanes inbound and two lanes outbound)
- a three lane road (one lane inbound and two lanes outbound), or
- a modified two lane road with a wide shoulder that can be adapted to provide two lanes outbound and a path for inbound emergency vehicles along the opposite shoulder. This sometimes called contra-flow traffic. We see it in use as tidal flow in peak hours in some cities.

Of these options the first two are likely to be the most effective. The third option requires more traffic control to manage the contra-flow and may only be practicable over relatively short distances of say one to three kilometres.

Whichever option is used it must be recognised that dual lane outbound flow only increases overall traffic capacity if the volume of traffic responding to a flood warning exceeds the nominal capacity of a single lane (see A Limit to Warning Speed and traffic flow below) **and** if traffic streams stay separated until well beyond the flood affected area. If the two lanes have to merge into one lane and it is intended to maintain 600 vehicles per hour flow out of the area being evacuated, the excess traffic (i.e. 300V/hr) must be diverted into a suitably sized holding area e.g. two hours of convergence equals 600 vehicles to hold.

If the third option (contra-flow) is to be implemented, it is suggested that estimation of dual lane outbound flow should be restricted to no more than 50% of total traffic volume. This allows for anticipated inbound residents traffic flow in the early stages of a flood. In any case, the dual outbound flow must be limited to the capacity to store excess traffic at any convergence point if the two lanes merge as described above.

2.2.4.2. A Limit to Warning Speed and traffic flow

There is a critical inter-relationship between warning and traffic flow. The warning process must be capable of motivating people to respond at a rate that will be consistent with potential traffic capacity. If warning is too slow, the routes will be under-utilised and evacuation may fail. On the other hand, if warning is too fast or is poorly sequenced, evacuation traffic may simply create gridlock.

In a concurrent time line, warning can theoretically be reduced to as little as one hour or less assuming enough door knocking teams are available or some technology delivers instantaneous warning however this outcome is likely to be futile because traffic flow capacity will dominate the operation. This means that in practical terms there is a break-even point beyond which there is no point in speeding up the warning process because people cannot get out of the area faster than the traffic can be moved.

It is also the case that traffic flow may not reach the potential capacity of the evacuation route/s if people cannot be motivated into responding at a sufficiently fast rate. For example, if census data shows an average of 1.5 vehicles per dwelling in the area, the minimum door knocking rate must be 400 dwellings per hour per traffic lane to create a demand of 600 veh/hour/lane(traffic flow rates are discussed below). At five minutes per dwelling the number of teams needed is 400/12 = 33 teams per lane. This is equivalent to about 70 personnel including control staff.

2.3. Safety Factors in Planning Evacuation Operations

In almost all fields of planning, design and construction, especially those involving risk to human life, a safety factor will be used to ensure that the design specification for structures or systems has a capacity to deal with uncertainty or unknowns that could result in failure. The magnitude of a safety factor will generally be based on a balance between the limits of reasonable cost to the community and the consequences of failure.

In the case of planning for flood evacuation operations, where total available time is the critical issue, there should be a safety factor of extra time beyond what is considered the minimum required. This is necessary to allow for unexpected problems resulting from such things as: difficulty in the prediction of the timing and/or magnitude of the flood; human behaviour in response to flood warnings; or the complete loss or extended blockage of a critical evacuation route where no alternative route exists. Considering the serious consequences of the failure of an evacuation operation, identifiable safety factors have to be built into the flood emergency response planning and the systems and infrastructure that support it.

Safety factors will be most critical when time line analysis is being used to reverse-engineer the flood operation to determine the maximum safe size of a new urban development on a floodplain. The pressure on the emergency manager will be intense because the shorter the apparent time frame required for emergency response operations, the more new development is possible. Every hour that is allocated to a safety factor or response task could be converted into more homes or may represent a cost for better roads or facilities.

The expected duration of some elements of an evacuation operation can be estimated using some basic mathematical formula. Examples are the time needed to move vehicles along a road or the time required to warn a population living in a certain number of dwellings. Other elements, such as how long it will take to develop a firm prediction of flood severity, the time needed to mobilise resources, or the time it will take for a community to comprehend and respond to warnings, can only be estimated on the basis of experience.

It is important to recognise that using slightly conservative time estimates, for example not being too precise with the results of formula by rounding the results up, is not the same principle as providing a defined safety factor. Multiplying the formula result by a specific value of say 1.5 or two, or adding a specific additional time delay is creating a clearly identifiable safety factor.

A safety factor can be either integrated into the basic calculation or added to the estimated time. It has been suggested that only one safety factor is needed for a time line but it is considered best to clearly identify each component of the overall safety factor so as to make it easier to see how the total result was calculated and to permit experimentation and fine tuning as exercising and real events provide feedback. It is strongly recommended that safety factors be shown as separate, well defined and visible elements.

2.3.1. A Safety Factor for Flood Prediction

In the context of the time line it is not considered possible to provide a safety factor in the flood prediction process to account for the reliance on flood predictions as the trigger for evacuation. There may be safety features within the flood prediction process such as back-up rainfall gauges and back-up computer models, indeed, these should exist. These safety features do not constitute a safety factor because they do not represent a reserve of time to compensate for the delay a system failure may cause in the issuing of a flood prediction. In a practical sense, the evacuation time line cannot begin until a prediction is issued. The adoption of the QPF Limit discussed above appears to provide the best approach to dealing with prediction uncertainty. It is therefore, critical to ensure that the location of the development, the urban design and the supporting evacuation routes provide a safety factor adequate for the prediction environment.

2.3.2. A Safety Factor for Decision Making and Mobilisation

As is the case for flood prediction, it has not been found to be possible to develop a safety factor for decision making and mobilisation. It is considered sufficient to use the best estimates of the emergency services to plan the duration of this element. The critical issue is to guard against attempts by non-emergency service interests to force the adoption of unrealistically short time periods for this complex element of the time line.

2.3.3. A Safety Factor for Warning

The method used to determine warning time is a door knocking time calculation and is based on an average time per dwelling and does not include a safety factor to account for different responses to the warning. Depending on the circumstances being analysed it may be prudent to specifically add a warning acceptance safety factor.

Evacuation warning and particularly the human responses to such warnings involve inherent tendencies to under-react or delay in the hope that the situation will improve and a response may be avoided. This is an area of uncertainty but the SES's experience suggests that there will be a general reluctance to accept the validity of a warning until people can see some evidence of flooding. In the case of a severe flood in many NSW coastal valleys and other similar situations, waiting that long will be too late!

This response inertia must be expected and allowed for in the planning stage. Depending on the expected environment of an evacuation, consideration should be given to allowing for a nominal time delay between the start of warning delivery and the start of the required human response to the warning. This delay is referred to as the **Warning Acceptance Factor (WAF)**. and is not the same as the WLF discussed above. The duration of this WAF must be determined according to the expected environmental cues that would drive the human response.

If a warning has to be delivered at a time when the river may not have started to rise it could be expected that people will wait some time before deciding to respond. The WAF should be perhaps as much as a few hours. In other cases when warning will coincide with obvious environmental cues the WAF could be considered to be zero. A minimum value of one hour may be prudent.

Adopting both the one hour WLF and minimum one hour WAF, evacuation traffic is assumed not to begin to flow until at least two hours after the warning period commences and is assumed not to be completed earlier than one hour after the last dwelling is warned (the WLF). It is considered unlikely that the WAF would also need to be added to the end of the warning period (as must the WLF) because of the community momentum that should have developed by the end of the warning period.

In view of all of the above discussion on warning it is suggested that the minimum warning time that should be adopted for planning is three hours, comprising one hour warning delivery plus one hour WAF followed by one hour WLF.

2.3.4. A Safety Factor for Vehicle Movement

To allow for the delays that would be caused by a major traffic incident or a tree/power line falling onto the road, a specific **Traffic Safety Factor(TSF)** must be added to the calculated traffic movement duration.

To account for and the time needed to attend to a serious traffic incident and get traffic flowing again, it is considered that the minimum TSF is one hour. The following table is suggested as a guide the selection of a TSF for different traffic flow durations.

Table 1 Evacuation Traffic Flow Traffic Safety Factors

Base Time (Hours)	Safety Factor (hours)	Total Time (Hours)	Base Time (hours)	Safety Factor (Hours)	Total Time (hours)
1	1	2	9	2	11
2	1	3	10	2.5	12.5
3	1	4	11	2.5	13.5
4	1.5	5.5	12	2.5	14.5
5	1.5	6.5	13	3	16
6	1.5	7.5	14	3	17
7	2	9	15	3	18
8	2	10	16	3.5	19.5

It will be noticed that the TSF tends to be proportionally larger for short flow durations (e.g.100% of the one hour flow time). Referring back to the average rate of traffic flow i.e. 600 vehicles/lane/hour, the average flow rate would be more likely to be achieved over longer periods than would be the case for very short periods. In any evacuation, traffic flow will take time to ramp-up as the level of community response to the warning increases. For this reason it is considered that the one hour safety factor that is applied to the flow times of one to three hours is not excessive.

2.3.5. Constraints and Opportunities for Creating an Overall Safety Factor for Evacuation

It is only possible to have a high level confidence that the anticipated complete flood evacuation of a community is possible during a severe flood if there is an overall safety factor. In terms of trying to achieve a safety factor the following constraints and opportunities may apply:

- The time frame in which the BoM can make predictions based on measured rainfall will be catchment specific. Where possible it is obviously better if evacuation decisions can avoid reliance on QPF (see 2.3.1). This means that the evacuation operation should fit within this time frame unless a higher level of risk of un-necessary evacuation is to be accepted;

- SES flood experience during actual floods, exercises and planning work indicates that the time allowance for decision making, resource mobilisation and warning cannot be safely reduced below a planning figure of nine hours minimum (six hours decide and mobilise plus minimum of three hours warning and traffic).
- Because of uncertainty about human behaviour, validated by flood experience over recent years, there is a very high risk in planning to allow less time for flood warning than that estimated for doorknocking. Faster warning methods may produce a faster response on the day but cannot be relied upon at the planning stage (see 2.3.3);
- The construction of suitable roads with sufficient lanes at appropriate levels and grades to delay the time at which roads will be overtopped and rendered unusable by flooding during an evacuation, has the greatest potential to create sufficient reliable evacuation capacity with the required safety factor (see 2.3.4);
- Contra-flow traffic arrangements will be complicated to manage and are not a reliable alternative to dedicated outbound lanes.
- Multiple exit points from a site do not increase outbound capacity unless each exit links to its own independent evacuation road lane leading to an area beyond the PMF extent.
- Unless expert written advice to the contrary is obtained, the maximum traffic flow rate used in planning should not be higher than 600 V/hr/lane (see 2.3.4);
- Failure to apply improved urban subdivision design with landforms graded to prevent localised stormwater flooding of streets and internal trapped areas (islands) will frustrate or even destroy the benefits of works to create an evacuation safety factor;
- The scale of development (number of dwellings and businesses) may be limited by the physical constraints listed above. If the required evacuation capacity cannot be created, the number of people to be evacuated will have to be reduced to a point where existing capacity is sufficient.

3. Application Of Time-Line Analysis

For the purpose of comparison of different time line results it is desirable to nominate a common reference point and baseline set of conditions. For example, in the analysis of the impact of planned urban growth, the time line analysis of the evacuation of the population under the pre-development conditions has been found to be a useful baseline. The result of the assessment of the baseline environment for an area establishes what is called the **Flood Risk Status Quo Line (FRSQL).**

The FRSQL represents the starting point of the minimum time period needed to provide a reasonable level of confidence that the complete evacuation of an area is possible. The time period will include ALL decision making, mobilisation and community actions. For either an existing or proposed development, the FRSQL may fall outside what is considered an acceptable position in terms of risk and uncertainty, especially in terms of available flood warning time. The time line can show the extent of this departure from the preferred FRSQL position and this is expressed as an **FRSQL variation** in hours. The variation can be negative if there is a time deficit, or it can be positive if there is an apparent excess of time – in reality an improved safety factor.

In terms of flood emergency risk management the desirable result will be when the FRSQL coincides with the point on the time line where a flood prediction no longer relies on predicted rainfall i.e. the FRSQL coincides with the QPF limit. In practice it is likely that it will only be possible to ensure that those elements that directly involve the community ie warning and vehicle movement, fit above the QPF Limit. This means that the SES and their response partners may have to make the decision to mobilise on the initial uncertain QPF-based flood prediction.

Since 1997 the NSW SES has been asked to consider a number of floodplain urban development proposals in the light of the latest understanding of the flood emergency management issues and floodplain risk management. In particular the Service has been asked to assess the scale of urban development (the possible number of dwellings) that would fit within the flood warning time frame specified by the Bureau of Meteorology (see Annex A). A development scale that fits within the BoM time frame may be considered to represent the flood emergency risk management base line against which other development scenarios can be assessed.

Annex B, Annex C and Annex D show three of the results of the application of the time line concept to the analysis of urban development scenarios for Pitt Town in western Sydney(HCC, 2003). The time lines include analysis of the Richmond and Windsor areas because the whole area is affected in the same flood event and the relationship between them is important.

For the SES the purpose of the analysis was to determine the scale of urban development for the Pitt Town site that satisfies an initial risk assessment based on current flood warning and emergency response capability. It is stressed that the final decision about the acceptability or otherwise of any proposed development rests with Council and the community. The SES set out only to determine if evacuation was possible within reasonable emergency management risk limits, not to determine if such an evacuation requirement was acceptable to the community.

The analysis determined the maximum number of dwellings that can be managed within the BoM flood prediction time frame without relying on forecast rainfall and with the warning and vehicle movement elements of the evacuation operation taking place concurrently (concurrent time line).

A number of assumptions have been factored into each analysis:

1. The vehicle numbers used in the calculation is based on a vehicles to dwellings ratio (VDR) determined from census data (2.18 veh/dwelling).
2. The starting point for measuring elapsed time on the time-line (time zero hours) is the result of discussion with the Bureau of Meteorology (BoM). The BoM has indicated that that severe flooding could be predicted in the Windsor area using measured rainfall (no QPF) about nine hours before a flood is likely to exceed the level of the first major evacuation route at 14.14mAHD.
3. The QPF limit for Pitt Town is based on their local evacuation route at 16mAHD.
4. The relationship between height and time base is derived from an assumed average rate of river rise of 0.5m/hour. This rate of rise has been observed in many floods and is also observed in the hydraulic models used to simulate both past real flood events eg the 1867 flood of record and design floods up to and including the Probable Maximum Flood (PMF).

   NB: Work undertaken by Sydney Catchment Authority to study the effect of extreme rainfall events on Warragamba Dam has shown that short duration, faster rates of rise may be possible. Rates of up to 1.5m per hour could occur but the data from this recent work is still under review and has not yet been incorporated into the analysis shown in this report.

5. The warning time has been calculated using an estimate of how long it would take the specified number of two-person teams to physically knock on the door of each house. The SES has included realistic increases in resources for the larger growth scenarios.

The FRSQL condition chosen for the Pitt Town analysis is one that indicates that the components of a flood evacuation operation that involve action by the community (excludes decision making and SES mobilisation) must fit within the time between the QPF limit nominated by the BoM (see 2.3.1) and the closure of the evacuation route(16mAHD). For this site the time available above the QPF limit is about nine hours for a flood that would exceed the 1%AEP flood level of 17.3mAHD.

The results of the three scenarios shown are summarised below.

3.1.1. Evacuation Risk for the Existing Population

Looking at the diagram in Annex B it can be seen that for the existing Pitt Town population of 358 dwellings, the FRSQL is about 3.5 hours before the QPF limit. The warning and traffic elements can start about 2.5 hours after the QPF limit and end right on the limit of the evacuation time (route flood level of 16mAHD). This indicates that the existing development is within reasonable emergency management risk limits. It is stressed that community may have a different view about the level of risk and this is not assessed.

3.1.2. Scale of Development Exceeds Evacuation Risk Limits

Looking at the diagram in Annex C it can be seen that when 1405 new dwellings are added to the town, without changing the evacuation capacity, the FRSQL has been pushed back to six hours before the QPF limit. The scenario assumes an increase in SES warning resources from ten teams to 21 teams but as previously discussed, the warning and vehicle movement cannot start earlier than the QPF limit. The result is that the end point of the required evacuation time exceeds the available time by 2.5 hours (ie the route at 16mAHD could be cut by flooding 2.5 hours before evacuation is completed).

3.1.3. Scale of Development Matches Evacuation Risk Limits

Looking at the diagram in Annex D it can be seen that the maximum number of new dwellings that fits within the defined risk limits is found to 730. This requires the SES to increase warning teams from 10 to 17, an increase the Service was prepared to commit to. The other major concession on the part of the SES is acceptance of the FRSQL being redefined at six hours before the QPF limit, a shift of 2.5 hours into the area of lower prediction uncertainty. Although the SES may be prepared to accept this increased level of uncertainty, the community may express a different view.

The Hawkesbury City Council has proposed that if the growth of about 730 new dwellings proceeds, it will require the evacuation route to upgrade to a new minimum height of 17mAHD. This decision is a sensible, safety orientated condition that will return the post development FRSQL back to almost the pre-development situation.

4. Conclusion

The use of the evacuation time line analysis provides a practical method of planning for evacuation responses and as a communication tool when explaining evacuation operations to other participants in the planning process. Based on the author's experience to date, time line analysis is likely to show that for many existing communities, if evacuation decisions will have to be triggered using flood predictions based on highly uncertain forecast rainfall. If decisions are delayed until the flood can be predicted with some certainty based on rain that has actually fallen, there may simply not be enough time to evacuate. Past urban planning, if it has considered the flood risk at all, has clearly not taken into account the flood evacuation aspects of flood risk.

The time line is proving to be very useful when assessing the impact of urban growth on existing flood risk communities and for assessing the flood evacuation risk of greenfield development proposals. A new urban development must provide adequate time for emergency services to mobilise, time for a high quality warning service, time for people to prepare, and time for people to leave in an orderly and safe manner. In addition, there should be a reasonable expectation that the evacuation is being conducted for a good reason. This last point requires that the scale of a new urban development must not force emergency services and the community into making decisions about evacuation before there is a level of confidence about the severity of a developing flood. The time line can be used to explore these relationships.

Within the SES work to automate aspects of the time line calculations using spreadsheet modelling continues. In recent work with the SES and the DIPNR to assess the evacuation risk for the Proposed Penrith Lakes development, Molino Stewart and Sinclair Knight Merz also developed an evacuation traffic analysis spreadsheet model based on the time line discussed in this paper.

Another interesting area of work within the SES is in the translation of the time line results to an interactive operational display that uses real-time river height data to dynamically redraw the time lines for an actual flood evacuation operation. The evacuation time line tool continues to evolve based on suggestions of interested colleagues and in particular, a growing understanding of the underlying issues that the time line represents.

5. References

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NSW State Emergency Service (SES), 2000 - *Draft Hawkesbury-Nepean Flood Emergency State Plan.*

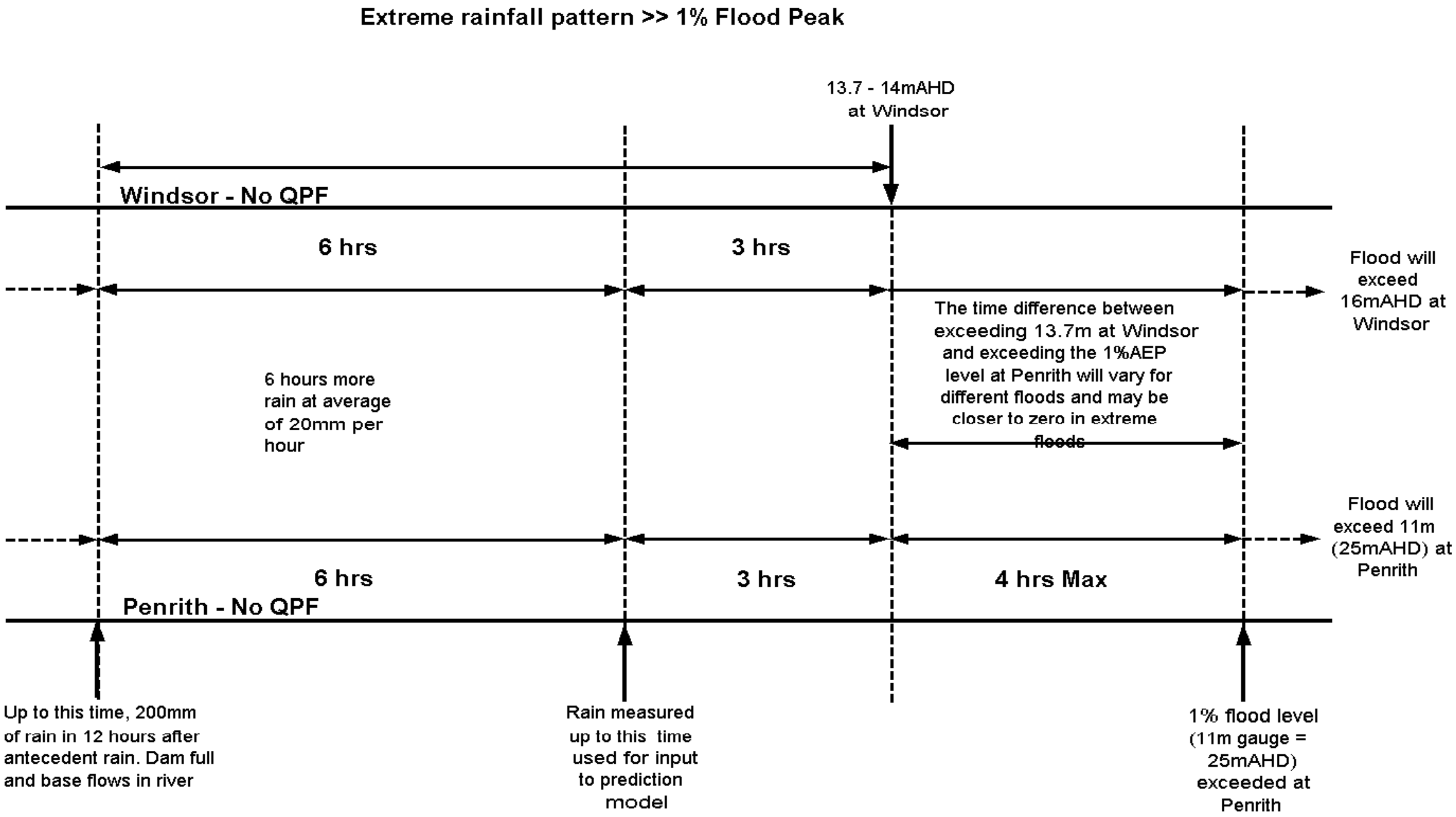
6. Acknowledgments

The development of the concepts discussed in this paper has benefited greatly from the contributions and constructive criticism of a number of people both within the NSW SES and from other agencies and private companies. In particular the author wishes to acknowledge the help of Peter Cinque (Division Controller Sydney Western), Chas Keys (Deputy Director General NSW SES), Patrick Clague (Manager Operations and Communications NSW SES), Steve Frost (Department of Community Services), the members of the Hawkesbury-Nepean Project Team within the NSW Department of Infrastructure Planning and Natural Resources (Arthur Low, David Avery, Catherine Gillespie, Sandra Wilson, and Marcus Walsh), and Steven Molino (Molino Stewart Environmental Services).

Paper presented at the 44th annual conference of the Floodplain Management Authorities of NSW, Coffs Harbour, 2004.

Annex A Example of Prediction Timing

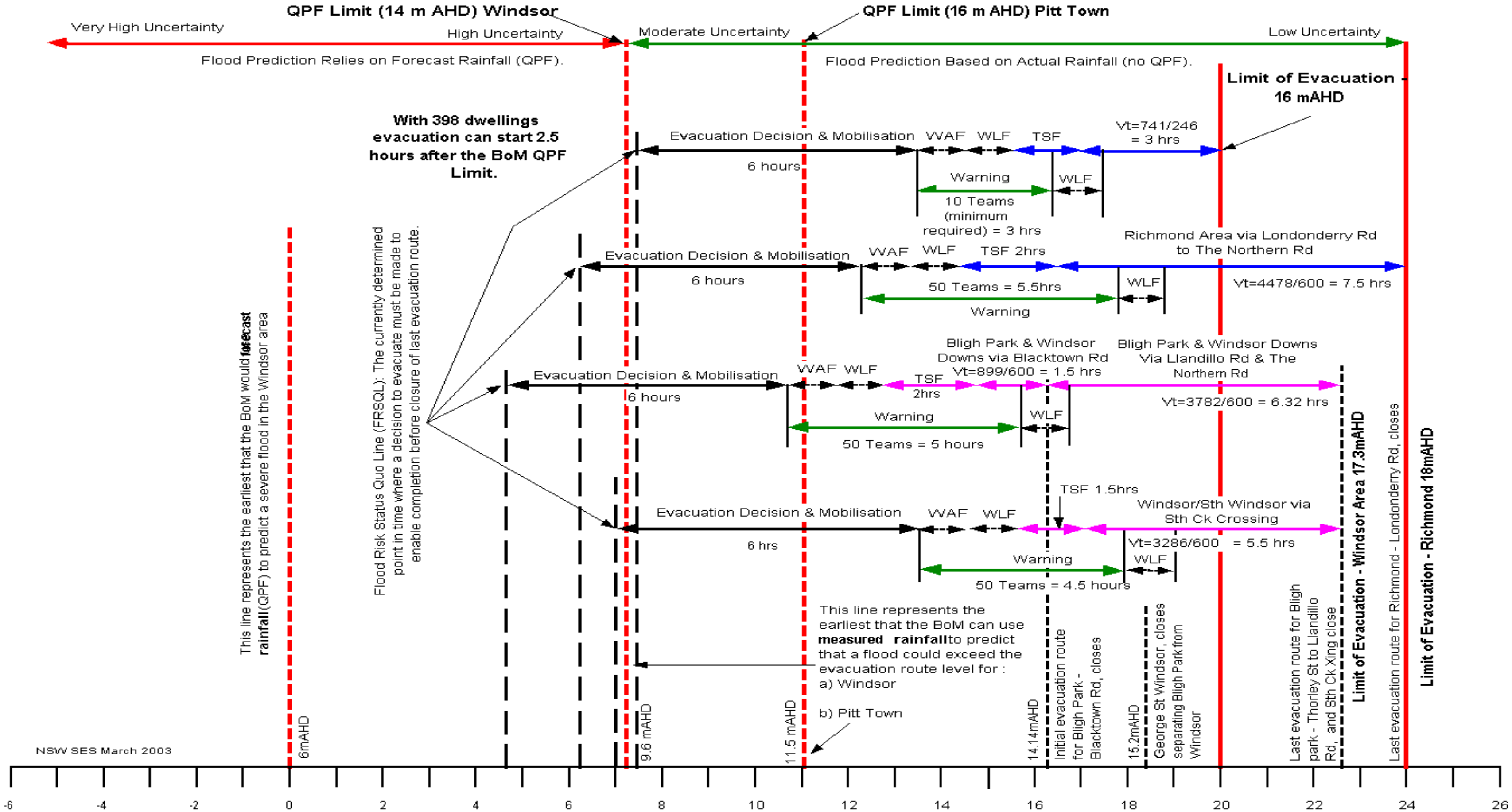
Time line of flood prediction using measured rainfall when the peak is a "bit" above the 1% flood at Penrith



This diagram is reproduced from a hand drawn version developed during discussion bewteen the BoM and the SES on May 13th 2002

Annex B Concurrent Time Line – existing population

Time Line Analysis of Flood Evacuation for Pitt Town - 358 Dwellings (existing zoned lots) & the Richmond Windsor Area, Warning & Traffic Flow Concurrent - 10 Warning Teams

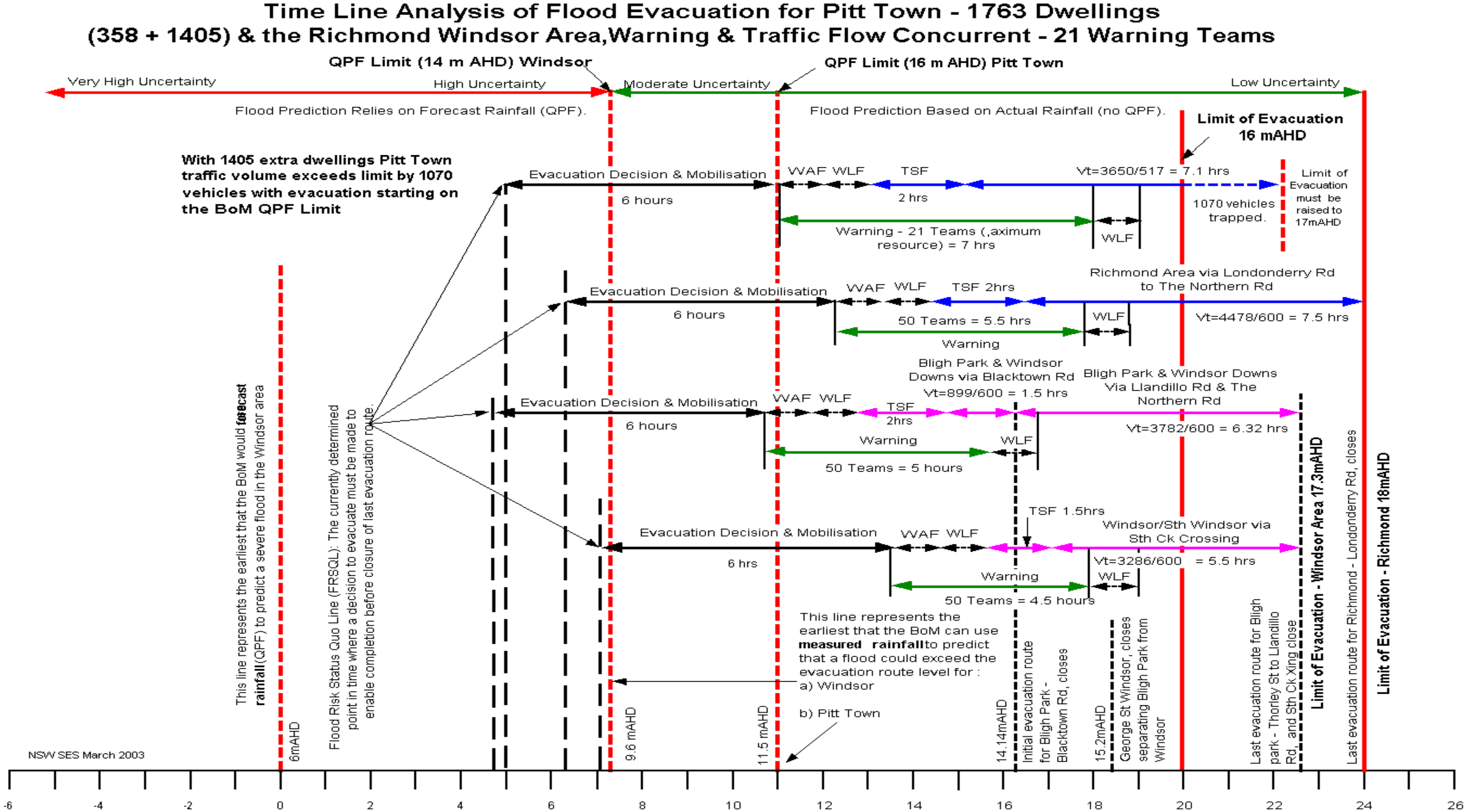


Elapsed time (hours) relative to BoM Flood Prediction Capability Heights (mAHD) are indicative of flood height at the corresponding time. Assumes average rate of river rise of 0.5m/hr

KEY

- **AHD** : Australian Height Datum, approximates the height of a point on the earth's surface above sea level
- **Vt**: Vehicle flow time based on total vehicle number divided by route capacity in vehicles per hour e.g. Vt = 1345/600 = 2.2.4 hours
- **TSF** : Traffic Safety Factor, a time proportional to overall traffic flow, to allow for complete stoppage of traffic flow
- **WLF** : Warning Lag Factor - 1 hour between start of warning & expected movement of first vehicles OR end of warning & expected movement of last vehicles - to allow for preparation time by residents
- **WAF** : Warning Acceptance Factor - To allow for expected reluctance of residents to accept reality of evacuation call in the very early stages before flooding is obvious
- **QPF** : Quantitative Predicted Rainfall - a meteorological estimate of future rainfall (quantity, spatial & temporal distribution), based on the output from weather system models.

Annex C Concurrent Time Line – excessive growth scenario



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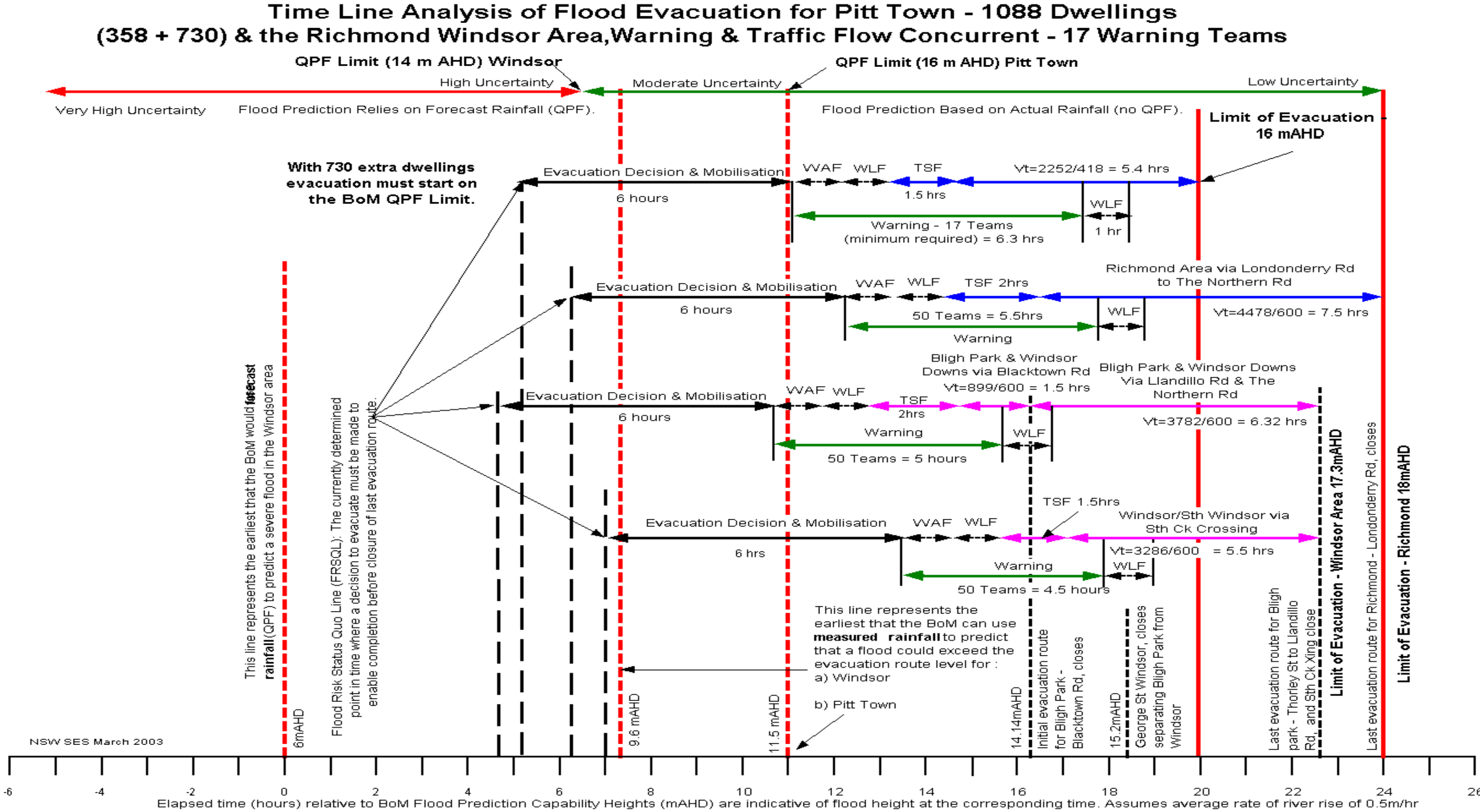
QPF : Quantitative Predicted Rainfall - a meteorological estimate of future rainfall (quantity, spatial & temporal distribution), based on the output from weather system models.

Annex D Concurrent Time Line – maximum acceptable growth scenario



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