PITT TOWN

LOCAL ENVIRONMENTAL STUDY

FLOOD EMERGENCY RISK MANAGEMENT

REVISED ANALYSIS OF

URBAN GROWTH IMPACT

REVISION 1

NEW SOUTH WALES STATE EMERGENCY SERVICE – April 2003

Table of Contents

List of Tables

List of Figure

1. Introduction

Reason for Revision

This report was circulated to Hawkesbury City Council, Connell Wagner and SES for comment in January 2003. Since that release, an issue has been identified that affects the working of the SES's Evacuation Time Line Analysis model used in the January report. As a consequence, it has been necessary to re-calculate the evacuation analysis and the results now differ from those printed in the January 2003 version of the report. The January 2003 version of the report should be discarded because the results in it are in-valid. In the same way, the even earlier April 2002 report for the Pitt Town LES has been superseded

Introduction

In April 2002, in response to a request from Hawkesbury City Council, the NSW SES provided comment on the flood emergency risk management implications of urban growth in the Pitt Town community. In the context of the production of a Local Environmental Study (LES) for Pitt town, the Service was asked to consider three different scenarios for future urban growth defined by the following numbers of new dwellings; 450, 685, and 1350.

The assessment was undertaken using a method developed by the SES called Evacuation Time Line Analysis. Since developing the evacuation time line concept in 1996 the SES has continued to develop the evacuation time line model which formed the basis of the April 2002 Pitt Town report. The Service has also been carrying out detailed analysis of evacuation operations for other flood response management and urban growth settings such as the Penrith Lakes Development. As a result of this continuing research and investigation the Service has come to the view that the original sequential time line model needs to be replaced by a model that better reflects the temporal relationship between elements of the flood evacuation. Coincidently, some of the respondents to the LES exhibition also questioned the way the SES time line represented such elements.

The new evacuation analysis model is called a concurrent time line and this explicitly models the fact that in real flood events, key elements of the time line, particularly warning and community response to warnings, will occur concurrently and not as independent sequential events. The time line concept is described in more detail in later sections of this report.

Another significant development in understanding the flood problem has resulted from the interaction between the SES and the Bureau of Meteorology (BoM) in the context of the Penrith Lakes Development. The way in which the flood warning time frame for a location is defined and measured is critical to being able to undertake a reasonable evacuation time line analysis. In trying to come to terms with the issue of uncertainty in flood height predictions the SES has learned about a crucial connection between weather forecasting and flood height prediction.

The BoM can predict flood heights based on either rainfall that has been measured by rainfall gauges in the river catchment OR it can predict flood heights using forecast rainfall known as Quantitative Precipitation Forecast (QPF). It is the amount of warning lead time and prediction uncertainty that distinguishes the two methods from one another. The implications of the use of QPF on time line analysis are also discussed in more detail later in this report.

In addition to the changes in the time line model and the issue of QPF, other issues have been identified during the period of LES exhibition. In particular there has been feedback suggesting that the some of the data inputs to the time line model were not correct. It appears that both the size of the existing population living in Pitt Town and the potential for an increase in the population based on the number of existing lots zoned for urban growth were underestimated. These discrepancies result from the difficulty in defining boundaries when aggregating or subdividing numerical census data and council cadastral data. Different studies have used different methods with data variation being the result and the SES has had no choice but to rely on the data from these studies. There has also been some uncertainty on the part of the SES as to the numerical value of the growth scenarios.

For all of the above reasons the need for a review of the April 2002 SES report is indicated. Much of the general content of the April 2002 SES report remains valid and to avoid confusion between versions of reports, all of that material is repeated in this revised report. The April 2000 report should be considered in-valid because of the revised methodology.

2. Summary of Results

Following on from the public exhibition of the Local Environmental Study (LES) for Pitt town, the NSW SES has been asked to review the flood emergency risk management implications of urban growth in the Pitt Town community. The LES exhibition material included the SES's April 2002 report. The Service has now been asked to consider three different scenarios for future urban growth defined by the following numbers of new dwellings: 495 (originally 450); 730 (originally 685), and 1,405 (originally 1350). Taking into account update figures provided by Hawkesbury City Council, the existing population for the purpose of a base line for an evacuation time line analysis is now set at 358 lots compared to 210 in the April 2002 SES report.

The analysis by the Service indicates that none of the growth scenarios can be accommodated without the need for more SES resources. In the case of some scenarios, both more SES resources and evacuation route upgrading will be necessary. The requirements that must be met in order to accommodate the flood evacuation for the growth scenarios to the satisfaction of the SES are summarised in Table 1 below.

Table 1 Summary of Growth Scenario Evacuation Requirements

Scenario (Number of lots)	SES personnel needed	Requirement that must be met. (Both columns apply)		Resource demand acceptable to the SES
		Additional SES personnel	Evacuation route upgrading	
358(Existing)	25	0	None	Yes
1) 358+495	35	10	None	Yes
2) 358+730	50	25	None	Yes
3) 358+1,405	50	25	Raise 1m	Yes
4) 358+1,000	50	25	None	Yes
5) 358+1,235	**60**	35	None	**No**
6) 358+1,235	50	25	Raise 0.7 m	Yes

Growth Scenarios 1, 2 & 4 can be accommodated within the existing evacuation route construction and within the acceptable limits of increased demand on SES personnel. In contrast, even with the maximum acceptable increase in demand on SES personnel, growth scenarios 3 & 6 can only be accommodated if the minimum RL of the evacuation route within the PMF extent is raised (by 1 metre to RL 17 m AHD & 0.7 m to RL 16.7 m AHD respectively). Scenario 5 is unacceptable due to the excessive demand on SES resources.

It will be noticed that three additional scenarios have been include in table 1 and that these were not requested in the LES brief. These are scenarios 4, 5 & 6 which are described below:

Scenario 4 is included because it is shows the maximum number of new dwellings that can be accommodated within the constraints of SES resources and the existing evacuation route. A 100% increase in SES personnel is required compared to that required for the existing potential population but this scenario should be manageable.

Scenario 5 represents the theoretical *maximum urban growth* for the existing evacuation route *assuming no limit is set on demand for SES resources*. The number of vehicles resulting from growth of 1235 lots is on the limit of both evacuation capacity (600 vehicles/hour) and flood prediction lead time (9 hours). It is evacuation route capacity, not warning time, that is the limiting factor in this or any larger growth scenario. It should be noted that to reach the maximum possible traffic flow on the existing route, 60 SES personnel will be required - an unacceptable 140% increase. Applying more than 60 SES warning personnel or using any warning method that could theoretically cause people to respond more quickly (sirens, telephones etc.), increases excess evacuation traffic demand.

Scenario 6 reconsiders the 1235 new lots of scenario 5 but assumes that 50 SES personnel are used, the maximum number acceptable to the SES. The existing evacuation route will have to be raised by 0.7 metres to a minimum RL of 16.7 mAHD. This route raising is needed to ensure the route stays open long enough for all vehicles to escape from the area before the road closes and a shrinking flood island is formed.

Implications of Demand on SES resources

The need to provide additional SES resources to Pitt Town must be considered in the context of the flood operations that will be affecting the entire Sydney basin at the same time as Pitt Town is being affected. The Service cannot agree to try to provide more than 50 SES personnel at Pitt Town, an increase of 100% over the requirement for the existing 358 lots. With 50 SES personnel growth scenarios 1, 2, 3, 4 & 6 are likely to be manageable but note that scenarios 3 & 6 also require significant evacuation route upgrading. The required increase in SES resources to manage scenario 5 is unacceptable.

The Service is well aware that flood warnings can be delivered using a variety of communication modes including technological solutions such as automated telephone dial-out, mobile Short Message Service (SMS) and even email, not forgetting traditional modes such as radio and television. These modes all have issues of reliability and all require a supporting infrastructure of inquiry handling such as a call taking centre because they cannot convey complex messages. Although the Service will use such modes, for the purpose of evacuation analysis, especially in the context of urban growth planning, door knocking is considered to be the safest, most easily measurable, most reliable and most effective means of warning.

The Service has undertaken the flood risk assessment with a focus on the risk to life. If an evacuation time line analysis shows that evacuation of an area is possible using door knocking, then with the addition of other warning modes, a real safety factor should exist. The Service will not accept that urban growth should be permitted when it relies on the capability and theoretical speed of technological warning modes in order to fit within the evacuation time line analysis constraints.

The other aspect of flood risk is property damage potential. An assessment of this issue is beyond the scope of the SES analysis and must be dealt with by Hawkesbury City Council through the broader floodplain risk management process as defined in the NSW Floodplain Management Manual.

Assessment Methodology

To undertake its analysis the SES has used a tool called a *time-line of emergency response for flood evacuation*. This tool has been developed by the Service during its' work in connection with the Hawkesbury-Nepean Floodplain Management Strategy. The assessment has considered the flood risk situation for the current population of Pitt Town and compared this result to an assessment of the flood risk for a number of growth scenarios added onto the current population. To provide a common reference point for all assessments, it has been assumed that no changes are made to the road level or capacity of the current evacuation routes out of Pitt Town. Each growth scenario does however assume some realistic increase in the amount of SES resource applied to the warning and evacuation management task.

The result of the assessment of the current population establishes what is called the *Flood Risk Status Quo Line* (FRSQL). The FRSQL represents the starting point of the time period needed to provide a reasonable level of confidence that the complete evacuation of all existing lots within Pitt Town is possible, assuming all lots are occupied. The FRSQL for Pitt Town equates to a flood height of 9.7 mAHD. In a flood rising at 0.5 m/hour, the 9.7 mAHD level could be exceeded approximately 13 hours prior to the river reaching 16mAHD, the lowest point on the current Pitt Town evacuation route.

The result of each of growth scenario assessment is expressed in terms of the time in hours by which the start time of the evacuation operation for the increased population varies from the current FRSQL. Assuming an average rate of river rise of 0.5m/hr, the FRSQL variation can also be expressed as an equivalent difference in road height. As an example, 1 hour is equivalent to 05m. If the variation is negative by 1 hour (a time deficit), then raising the evacuation route by 0.5m will bring the scenario back on to the current FRSQL, if that is the required outcome.

Also shown in the results is a QPF variation. This number indicates if the time required to warn residents and allow them to prepare and then drive their vehicles out is within the limits of the BoM flood prediction capability, <u>without relying on forecast rainfall</u> (QPF). A positive value is within the QPF Limit whereas a negative value is outside the QPF Limit. A negative QPF variation is not acceptable because of the high flood prediction uncertainty.

Of the two parameters, FRSQL variation and QPF variation discussed above, the QPF variation is a critical risk indicator. The SES considers it mandatory that it be possible to warn and evacuate a community within the QPF limit for the area. Warning and evacuation does not include SES decision and mobilisation time which is additional. For Pitt Town this means that the maximum allowable time requirement for warning and evacuation (column 5 in Table 2 below) is 9 hours including safety factors.

All growth scenarios require more time to be available for flood evacuation and this is to be expected given the increase in population. If growth occurs and nothing is done to increase the time available for evacuation, the relative flood risk for the existing Pitt Town population must have increased. The reason is that they will have less time available per dwelling than is the case pre-development. That increased risk may or may not be acceptable. The results of the time line analysis are summarised in the Table 2 below:

Table 2 Summarised Flood Risk Results of Concurrent Time-Line Analysis

Scenario Exist+new-SES	FRSQL variation (hours)	QPF Variation (hours)	Decide & Mobilise (hours)	Warning & Evacuation (hours)	Total Time (hours)	Within SES defined risk limit
358+0-25	0	2.5	6	6.5	12.5	Yes
1) 358+495-35	**-1.8**	0.7	6	8.3	14.3	Yes
2) 358+730-40	**-2.4**	0.1	6	8.9	14.9	Yes
3) 358+1,405-50	**-4.6**	**-2.1**	6	11.1	17.1	Yes
4) 358+1,000-50	**-2.4**	0.1	6	8.9	14.9	Yes
5) 358+1,235-60	**-2.5**	0	6	9.0	15.0	**No**
6) 358+1,235-50	**-3.9**	**-1.4**		10.4	16.4	Yes

Looking table 2 above, the FRSQL and QPF variations that are negative are shown in bold. For the Windsor area, assuming the new South Creek high level evacuation route is constructed, the evacuation decision will have to be made at a height of around 8.4 m AHD. The current FRSQL for Pitt Town is a height of 9.7 mAHD. The height difference of 1.3 m is equivalent to 2.6 hours. The SES will not consider a post development FRSQL for Pitt Town that is lower than that for the Windsor area. This means that any FRSQL variation of more than –2.5 hours in table 2 is not acceptable. Negative values of QPF variation are also not acceptable.

Scenarios 1, 2 & 4 are all acceptable and although they will require an increase in SES resources and an acceptance by the SES of an FRSQL lower than the current one, no evacuation route upgrading is essential.

Scenario 3 is outside the QPF Limit for Pitt Town by –2.6 hours meaning that without road upgrading, warning and evacuation would have to begin nearly 3 hours before the QPF limit. In addition it would be necessary for the SES to make the Pitt Town evacuation decision and commence mobilisation more than 2 hours before taking the same action for the Windsor area. In the context of risk created by new urban growth, this is not acceptable to the SES. To enable scenario 3, road raising of up to 1 metre must be implemented to ensure a minimum road RL of 17 mAHD.

Scenarios 5 is not acceptable because it is only within the QPF limit because of the assumed number of SES personnel used in the time line model (60 personnel).

Scenario 6 in which 50 personnel are assumed is acceptable to the SES but road raising of up to 0.7 metres must be implemented to ensure a minimum road RL of 16.7 mAHD.

The maximum possible lot yield for Pitt Town cannot be increased above 1,235 even with the evacuation route upgraded to the equivalent of two outbound lanes and one inbound lane. An extra lane has no impact until vehicle flow could exceed 600 per hour and this would require more than 60 SES personnel. For example, to accommodate 1,405 extra lots using an extra lane (instead of route raising) requires at least 70 SES personnel, well beyond the maximum resource demand acceptable to the SES. For the same reason, road widening has no beneficial impact in scenarios 5 or 6.

The Service's analysis has identified and quantified the difference in flood risk between the existing population scenario and the flood risk that would exist after the three growth scenarios. If the Council and the community accept the Service's methodology and decide that the existing flood risk is an acceptable benchmark, the flood risk variation can be used as an indicator of the impact of the proposed urban growth. If the flood risk variation is dealt with as suggested by the SES in this report, the Service will accept that in terms of flood risk, urban growth can take place.

Other Improvements to Support the Flood Affected Community

In the future there may be situations where, despite the flood emergency planning and physical works to lower flood risk, an evacuation operation is not completed leaving some people stranded by floodwater. This could be the result of flood behaviour or human behaviour or, it could be a deliberate strategy based on a clear indication that the Pitt Town flood island will be formed but will be mostly above the reach of the peak level of the flood.

In either situation it would be a distinct advantage to have adequate community facilities located on the highest part of the island. It is recommended that any permitted urban growth is supported by the development of a community hall or similar facility with the capability of operating independently (power and water) for several days after Pitt Town has been isolated by floodwater.

3. Introduction

This report has been prepared to assist Hawkesbury City Council in the preparation of a Local Environmental Study (LES) for Pitt town. The NSW SES has been asked to provide comment on the flood emergency risk management (FERM) implications of urban growth in the Pitt Town area. It has to be stated at the outset that the Service's experience with the flood problem in Hawkesbury-Nepean Valley over the period since 1990 has been characterised by frequent and sometimes dramatic change. The flood problem for this valley and the associated flood emergency management issues are among the most complex in Australia.

The Service must caution those relying on this report that the methodology used in our review and the comments presented in this review are based on our current understanding of the problem. Both the methodology and the understanding of the problem are almost certain to be refined in the near future. The focus of attention to date, initially through the flood emergency planning associated with the Warragamba Dam in 1990-1993 and since 1997 through the Hawkesbury-Nepean Floodplain Management Strategy, has been to try and deal with the flood risk exposure of the existing population within the Hawkesbury-Nepean Valley. To be required at this point in time to assess the impact of flood risk changes associated with future urban growth, before the work to deal with the existing risk has been completed or evaluated is less than ideal.

Managing the flood risk increase associated with urban growth will not be an easy task. The Service has provided a detailed explanation of the problem and given indications of measures that could be pursued if urban growth is to occur.

The SES is only in a position to comment on the likely flood emergency management outcomes of the proposed urban growth. The Pitt Town community and Hawkesbury City Council must decide whether the outcomes are acceptable and if the growth has real merit. Community involvement in such decisions should be consistent with the model framework for community emergency risk management (ERM), a nationally accepted application of the Australian Standard for Risk Management AS/NZ 4360:1999.

Community ERM application is described in the Emergency Management Australia (EMA) publication *Emergency Risk Management Application Guide, Australian Emergency Manuals Series, Part II, Volume I.* The ERM philosophy has also been adopted by the NSW State Emergency Management Committee and is in the process of being promulgated through local government area Local Emergency Management Committees. A NSW Implementation Guide based on the EMA publication is currently being distributed.

The Minimum Acceptable Flood Emergency Risk Management Outcome

There is a continuing flood risk for the majority of the existing residents of Pitt Town. This is the case even after work has been recently undertaken through the Hawkesbury-Nepean Floodplain Management Strategy to reduce the flood risk compared to what it was beforehand. Further risk reduction would be desirable if this is both socially and economically possible. Risk acceptance is a complex social issue but the Service is in a position to provide some advice to the community about the issue and must also use its knowledge and experience to try achieve some standards consistent with best practice in emergency risk management.

The Service is of the view that population growth must only be permitted under the following circumstances:

1. Any increase in flood risk for the existing population as a result of the growth is acceptable to the community and the SES, and
2. The flood risk of the total population after development must be within the limits determined by the SES.

This report does not attempt to assess the Pitt Town community's attitude to the flood risk issue mentioned above. That is a matter for the Hawkesbury City Council to determine through community consultation and the SES will participate in that process.

Although the following idea goes beyond the concept of a minimum acceptable outcome, it would be ideal if the compensatory measures to deal with urban growth could achieve some overall reduction of flood risk for the entire post urban growth population. That outcome would substantially increase the merit of the urban growth.

4. The Current Flood Risk Situation for Pitt Town

Pitt Town is one of a number of communities that will experience the unique flood behaviour associated with the Hawkesbury-Nepean river system. The river system has a huge catchment area starting as far south as Goulburn and as far west as Lithgow. The unique feature of the valley is that downstream of Pitt Town the river enters the Sackville Gorge, a dramatic and unusual narrowing of the valley. Most coastal rivers flow through progressively wider valleys and floodwater tends to spread out becoming less deep as the river approaches the coastal lowlands. On the Hawkesbury-Nepean river system this is not the case and in big floods, the constriction of the Sackville gorge causes floodwater to bank-up and form a large inland lake of extraordinary depth.

In the area around Windsor and Pitt Town the water could rise from the typical daily level of just 1.5m AHD up to over 26m AHD in the most severe of floods thought possible, the Probable Maximum Flood (PMF). In the flood of record in 1867 the water level rose to just over 19mAHD. Pitt Town, like its neighbours Richmond, Windsor and McGraths Hill is located on relatively high ground within the floodplain. While this offers some protection in less severe floods, in bigger floods this topography results in the high ground being surrounded by floodwater and turning into an isolated island with no way on or off except by boat or helicopter.

In the case of Pitt Town, levelling surveys show that an island will be formed when floodwater exceeds about 16mAHD, the lowest point on the evacuation route. This corresponds to a flood that should not be thought of as rare. Such a flood has around 1 chance in 60 of occurring in any year. Bigger floods will result in progressively smaller island area and there are only three small areas of ground likely to be above the reach of the PMF and then only by a few metres. This is different to and marginally better than the situation of Richmond, Windsor and McGraths Hill, all areas of which are below the PMF level and will be completely submerged in a large enough flood.

It is the island forming topography of Pitt Town that creates the unique emergency management problem. If a flood is threatening, a decision has to made very early about whether to evacuate people to safety by taking them off the floodplain. The evacuation of Pitt Town must use residents' own cars and this means all residents have to be out of the area well before floodwater cuts the evacuation route and creates the island.

To allow sufficient time for people to drive out after packing their essential belongings, the SES must have time to warn the community, time to put our resources into position before the warning can begin and some time has be allowed for the flood prediction and decision making processes. At present this means the decision to begin a full evacuation operation for Pitt Town must be made no later than when the river level at Windsor reaches 9.8 mAHD.

It will only be possible to make <u>a decision not to evacuate</u> when there is a **very high degree of confidence** that a developing flood cannot reach a height that would close the only escape route (less than 16mAHD) OR that if the route could be cut, then the majority of land on the island will remain dry at the flood peak. This presents the BoM, the SES and the community with a serious situation because the SES will have to initiate the evacuation <u>unless</u> the BoM can say with almost 100% certainty, that a developing flood will not exceed the level of the evacuation route. The evacuation decision cannot simply be delayed until more information is available.

Even if it was possible to consider not evacuating, the problem remains as to whether it is safe to leave a large group of people stranded on an island. The Service's experience is that isolated people often have problems that require urgent attention. This creates a big demand on emergency services at a time when they are already under stress from the wider flood emergency. Neither option is without some risks and costs that must be born by the community.

5. Analysing Flood Emergency Risk Management Problems

Identifying the effect of flooding on a community and documenting a range of response strategies is only part of the management solution. Selected strategies have to be capable of being implemented and during floods, managing time is fundamental to the success of any response operation. A failure to properly understand the issues related to time in a flood is likely to be the cause of response failure. In the most extreme case this could mean the failure to evacuate people away from a flood before the inundation of a community.

Since about 1997 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 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.

The process is basically as follows. A horizontal line represents how much time is expected to be available in a flood. 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 response what has to be done, when it has to be started, and approximately how long it might take during the flood scenario analysed.

Looking at the time-line in Diagram 1 the following points should be noted:

1. The time line does not 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;
2. The closure by flooding of the last useable evacuation route marks the end of the available evacuation time;
3. 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;
4. Each time element is shown as a discrete sequential element, this is called a **sequential time line**. It is recognised that in practice, some overlapping would occur, although this cannot be easily quantified. The time occupied by each element has a direct impact on the time available for all other elements. Treating elements as sequential is very conservative and has the advantage of building-in some safety factor;
5. If two or more elements of the time line are treated as being concurrent events by overlapping them, this is called a **concurrent time line**. The result will be inherently less conservative and this method must be used with caution. For the purpose of trying to make a realistic assessment of a scenario for response management however, the arrangement of some elements so that they are concurrent may be of benefit.
6. Warning and traffic movement are the elements most likely to take place concurrently in a real flood event. An exception may be where different areas are being warned at much

the same time but then have to be sequenced on to evacuation routes at specific times or in a particular order.

7. It is the flood durability and capacity of evacuation routes that has the greatest impact on total available time. If the total population in the area is to be increased, without having a negative impact on the existing population's flood risk situation, the evacuation route must be made to last longer i.e shift the end-point of the time line to the right <u>or</u> the number of available lanes must be increased i.e move more vehicles in the same time period.
8. If more people have to be to evacuated the time needed for warning increase and that additional time must also be found by upgrading the road/s. For the purpose of critical time-line analysis, the calculated warning time cannot be reduced by relying on technological approaches. Only door knocking provides a high degree of warning reliability. If technology does reduce warning time in a real flood event, that will be a safety margin bonus for the community.

Estimating Element Time Duration's

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 planning a new urban development for example, the estimates must be very conservative and reflect high standards of public safety. Consider flood warning as an example. It is probably true that people can be forced by law, or by the direct threat of a flood to evacuate their homes, with little or no time to prepare or save their belongings. However, it should be viewed as totally unacceptable to design a new urban area that would require people to have to behave that way in order to survive.

A new urban development must provide adequate time for emergency services to prepare, 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 a reasonable expectation that the evacuation has been conducted for a good reason. This last point requires that poor design of a new urban development must not force emergency services and the community into making decisions about evacuation before there is a high level of confidence about the severity of a developing flood. In this situation the time zero of the time line would have to be made earlier (shifted to the left on the line) but evacuation may then have to be triggered using flood predictions based on highly uncertain forecast rainfall.

When trying to prepare an emergency response plan for an existing urban environment where time availability may be restricted and cannot be extended due to physical, social or financial constraints, the time line may have to use very tight time estimates. It might be found for example, that even using flood predictions based on highly uncertain forecast rainfall, to get all people and their vehicles out in time, the warning time would have to be very short with no room for a margin of safety, despite the fact that this not best practice.

Time line analysis will often show that for many existing communities, if evacuation decisions are delayed until rain has actually fallen, by which time the flood can be predicted with some certainty, there may simply not be enough time to evacuate.

It is the flood durability and traffic capacity of evacuation routes that has the greatest impact on total available time. If the total population in an area is to be increased, without having a negative impact on the existing population's flood risk situation, the evacuation route must be made to last longer or have its capacity increased.. This could be done by raising the level of a route to delay flood closure <u>or</u> the number of available lanes could be increased i.e. move more vehicles in the same time period. Road raising has the effect of shifting the end-point of the time line to the right whereas road widening fits more traffic flow into the same time frame.

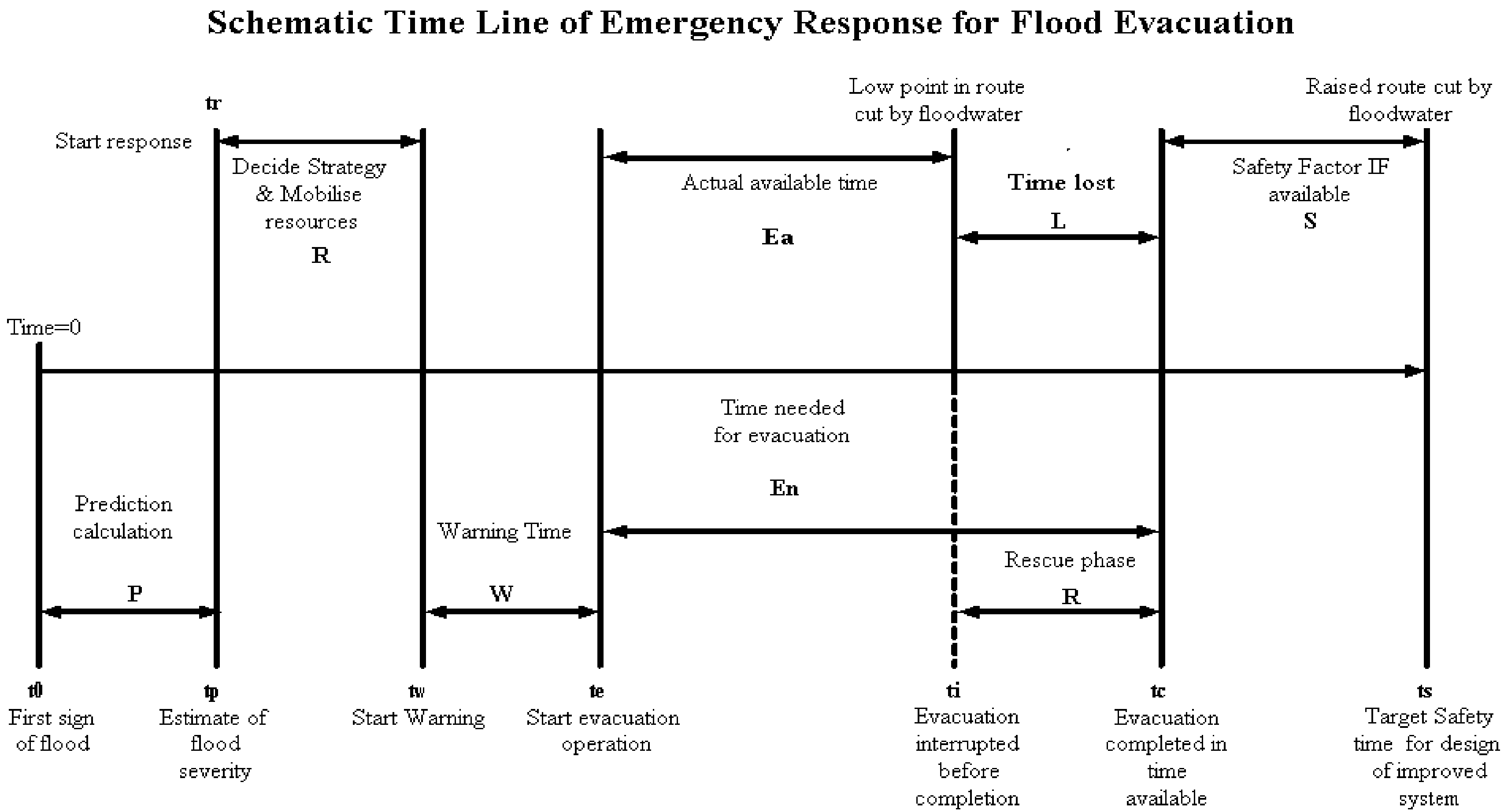
There is a critical inter-relationship between traffic flow and warning. The warning process must be capable of motivating people to respond at a rate that can utilise maximise potential traffic capacity.

The time needed to warn the population depends on how large the population is and how many emergency service personnel can be dedicated to the task of warning. It is very difficult to estimate how much time has to be available for the warning element, especially if trying to account for the use of so-called warning technology.

If the number of dwellings is increased, more people must be evacuated and the time needed for warning also increases. This additional time must generally be found by upgrading the evacuation road/s. For the purpose of time line analysis, the estimated warning time should not be reduced by relying on technological approaches or the uncertain outcomes of public flood education. Only door knocking provides a high degree of warning reliability in the context of planning the time frame for evacuation. If technology could reduce warning time in a real flood event, that will be a safety factor bonus for the community. The possible time saving of technological warning must not be converted into additional population, thereby destroying any safety factor.

These issues are discussed in greater detail in the section A Safety Factor for Flood Evacuation Operations in part 6, below.

Diagram 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:

1. **Flood Forecasting**

   – Represented by **P** in the diagram. Factors than can influence **P** include:

   a) Physical characteristics of he catchment;

   b) Data collection: methods, hardware, transmission;

   c) Flood modelling capability: data, software;

   d) Human resources: staff availability and activation time;

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

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

2. **Response Initiation & Mobilisation**

Represented by **R** in the diagram.

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.

3. **Warning Delivery**

Represented by **W** in The diagram.

Warning preparation and delivery could be expected to represent an element where significant time is required. The most reliable warning method is door-to-door delivery by emergency service personnel. This method has been field tested by NSW SES indicating an average of 5 minutes should be allowed per dwelling, per team of two doorknockers. In floods many other methods of warning may used including radio, TV, sirens, telephones but the time frame for these methods cannot be realistically assessed.

Prior public education is considered fundamental to the success of any warning strategy. A public education program using a variety of methods must be implemented to develop a flood aware community. Public education is a minimum requirement and the effectiveness cannot be measured with any benefit or failure only apparent after an event.

4. **Evacuation Operations**

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

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 cars, 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 flooding or failure of evacuation routes or transport systems.

Ea represents the actual (true time) available and within which evacuation must either be completed by adapting the process to the time constraints, or will have to be aborted before completion. The portion of evacuation not completed by time **te** will result in the need to begin a rescue operation. Rescue is failed evacuation!

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 meaning 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:

f) 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;

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

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

i) Removal of personal effects, pets, and livestock, from property before/during evacuation;

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

k) Marshalling and processing facilities for evacuees;

- Accident handling arrangements on evacuation routes.

6. A Safety Factor for Flood 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 some critical areas such as rescue equipment for example, a safety factor of up to 9 will used. Although a rescue rope may have a design tensile strength of 3,000 kg, in use it should never be subjected to a load of more than 333kg. The 333kg value is known as the safe working load (SWL). The SWL accounts for possible loss of strength through wear, material variation or deterioration, invisible damage and knots tied during use.

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 people can be placed at risk. Every hour that is allocated to a safety factor or response task could be converted into more homes.

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. Whichever method is used to arrive at an estimate of required time for each element of the evacuation operation, a safety factor must be either integrated into the calculation or added to the estimated time.

It is important to recognise that using conservative time estimates, for example not being too precise with the results of formula by rounding the results up to the nearest hour, is not the same principle as providing a safety factor. Multiplying the formula result by a factor of 1.5 or 2 or adding a specific additional time delay is creating a clearly identifiable safety factor.

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.

A Safety Factor for Flood Prediction

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.

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 can be completely inundated. The 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.

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. 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 report this point is called the **QPF Limit**.

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 report 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.

In the context of the time line it is not 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 issuing a flood prediction. In a practical sense, the time line does not begin until a prediction is issued. 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.

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.

The flood behaviour in the Hawkesbury-Nepean valley is characterised by an unusually large depth range - floodwater can rise up to 24 metres above normal river level, and by rapid rates of rise – an average of 0.5m/hr. The urban areas are located on island forming hills within the floodplain which are cut off from flood free high ground early in a flood.

These conditions place great demand on the Bureau of Meteorology (BoM) to provide very early predictions of flood severity. The assessment by the BoM and independent experts to date shows that the such early evacuation decision will have to be made before there is any obvious sign of even minor flooding in the lower valley. The initial flood height prediction will be based on rainfall forecasts i.e. using computer models of the weather systems before the majority of the flood producing rain actually falls. This is a highly uncertain environment for serious decision making.

The BoM has indicated that the river at Windsor is likely to have reached a height of 6 mAHD before there is any chance of indicating the possibility of serious flooding. Because of the gravity of the evacuation decision, the SES believes that where possible, a height closer to 10mAHD should be used as the starting point (time zero) for evacuation planning. Being able to safely wait until a height of 10m AHD, rather than the much lower height of 6mAHD will provide some protection against deciding to evacuate only to find later on, as more actual rainfall data is collected, that the flood does not reach the level of severity first anticipated.

A Safety Factor for Decision Making, Mobilisation & Warning

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. The plan will be the Hawkesbury-Nepean Flood Emergency State Plan in the case of the Hawkesbury-Nepean valley (SES, 2000). It will then be necessary to **mobilise** the resources needed and to communicate the planned intentions to the community (**warning**). These three elements are another area where a precise formula cannot be used to calculate the time requirements and safety factors. The experience of the Combat Agency - the SES – in managing floods must be applied to the problem.

Decision Making and Mobilisation

The amount of time that needs to be allocated for decision making and mobilisation of resources depends 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 population, it may be necessary to try and determine mobilisation time by conducting physical scenario-based exercises.

Warning

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

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 (McGraths Hill – July 2001) 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 respond. 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). At the present time it is not impossible to model these technology-based warning methods in the time line analysis. In situations where people would drown if not evacuated, the SES will have no choice but to doorknock every residence and time must be allowed for that.

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.

To which element the WLF is added to depends on the way the relationship between warning and vehicle movement is dealt with. If warning is treated as a discrete element that precedes the traffic movement element – a sequential time line, the WLF is added to the end of door knock warning time. If warning is treated as an element that takes place concurrently with traffic movement – a concurrent time line, the hour is added to the start of the traffic movement element. It must also be noted that in a concurrent time line there must be a period equal to the WLF between the end of warning and the end of traffic movement. In other words warning cannot end at the same time as or later than traffic movement.

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 great 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 the Hawkesbury-Nepean valley and many similar situations, waiting that long will be too late!

This response inertia must be expected and allowed for in the analysis. When using the concurrent time line analysis method, consideration should be given to allowing for a nominal time delay between the delivery of a warning 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 1 hour may be prudent.

In view of the above points it is suggested that the minimum warning time that should be adopted for planning is 3 hours comprising 1 hour warning delivery plus 1 hour WAF followed by 1 hour WLF.

A Limit to Warning Speed and Traffic Flow

In a concurrent time line, warning can theoretically be reduced to as little as 1 hour or less assuming enough door knocking teams are available or some technology delivers instantaneous warning. This outcome is likely to be futile however because traffic flow capacity will tend to dominate the operation. This means that in practical terms there is a break-even point below 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.

A note of caution is need here because 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. At 5 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.

Decision Making, Mobilisation and Warning Combined

Where the calculated warning period must commence below the QPF Limit, flood response planning should allow a minimum time frame of 12 hours to account for the combined purposes of decision making, mobilisation of resources and warning the community. If the time needed for warning exceeds 6 hours, then the minimum 12 hour period should be extended by the additional warning time in excess of 6 hours. For example, if warning time is 7 hours **and** has to commence below the QPF Limit then the total time required for decision making, mobilisation of resources and warning the community becomes 12 + (7-6) = 13 hours.

Where the calculated warning time interval can commence on or above the QPF Limit**,** the formula can be modified so that the time frame for decision making, mobilisation and warning is a minimum of 9 hours. This provides for a minimum of 6 hours decision making and mobilisation of resources and a minimum of 3 hour for warning (see warning above)

Both methods provide some safety factor by allowing 6 hours for the decision making and mobilisation elements based on past experience and flood exercises. In considering whether 6 hours is too long to allow for a site such as Penrith Lakes, it must be recognised that it is not possible to isolate the evacuation decision and mobilisation for this area from the overall context of a concurrent Hawkesbury-Nepean valley-wide flood operation. Penrith Lakes will be only one of many locations which will be subject to the need for evacuation in a severe flood during the same time period, requiring the mobilisation of a very large number of personnel and equipment.

A Safety Factor for Vehicle Movement

Before discussing evacuation route traffic capacity calculations, there is another issue that must be considered. This relates to localised storm water flooding of both internal streets and external roads used for evacuation. 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 had reached safety. During the implementation of the Hawkesbury-Nepean Flood Management Strategy a design standard of 1:500AEP has been adopted for storm water or creek crossings on critical evacuation routes

The emergency planning for vehicle movement is based on an average flow rate of 600 vehicles/hour/lane. This number is derived from a typical rural road design flow rate of 1200 vehicles/hour/lane, reduced by a factor of 2 (1200/2=600) to account for the adverse driving conditions such as heavy rain, darkness and driver unfamiliarity that will probably prevail in a flood. This reduction is not considered as a safety factor because it accounts for some of the expected traffic problems. For short traffic flow durations of 1-3 hours, the average may not be achieved. To allow for this possibility and the unpredictable delays caused by a major traffic accident or a tree/power line falling onto the road, a specific safety factor must be added to the calculated traffic movement duration.

To account for a serious traffic accident and the time needed to attend to it and get traffic flowing again, it is considered that the minimum safety factor is 1 hour. The following table is suggested as a guide the selection of safety factors for different traffic flow durations.

Table 3 Evacuation Traffic Flow Time 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 these safety factors tend to be proportionally larger for short flow durations e.g.100% of the 1 hour flow time. Considering the above table and 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 ramp-up as the level of community response to the warning increases. If the total number of vehicles was only 600, theoretically 1 hour for traffic flow, it is possible that the average might not be achieved. To do so may require a peak flow rate of 1200 vehicles per hour or more depending on the ramp-up rate and the traffic may take longer than 1 hour to leave. For this reason it is considered that the 1 hour safety factor that is applied to the flow times of 1-3 hours is not excessive.

Evacuation traffic is assumed not to begin to flow until one hour after the warning commences and is assumed not to be completed earlier than one hour after the last dwelling is warned- the Warning Lag Factor (see Warning above). This means that warning must be completed no less than 1 hour before the expected closure of the evacuation route.

It must be stressed that the upgrading work completed on existing roads in Pitt Town to date has been to deal with evacuation of only the existing population. The works were designed to produce two outcomes. The first was a reduction in the identified time deficit resulting from the low level of the original evacuation route (the 1997 studies). The second was a reduction in the risk of roads being closed by local storms before the main river flood even reaches them (also in the 1997 studies). Local storm closures could have delayed evacuation so much that time would run out before everybody had reached safety.

Dual lane Outbound Flow

In some circumstances it may be possible to design the road system to cope with dual outbound lane traffic flow. This could be done by providing:

- a conventional dual lane carriageway (2 lanes inbound and 2 lanes outbound);
- a three lane road (1 lane inbound and 2 lanes outbound); or
- a modified 2 lane road with a wide shoulder that can be adapted to provide 2 lanes outbound and a path for inbound emergency vehicles along the opposite shoulder.

Of these options the first two are likely to be the most effective. The third option requires more traffic control and may only be practicable over relatively short distances of say 1-3 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, above) 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. 2 hours of convergence equals 600 vehicles to hold.

If the third option 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.

Constraints and Opportunities for Creating an Overall Safety Factor

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

- It is not acceptable to require the making of an evacuation decision for Pitt Town earlier than the time at which a similar decision must be made for Windsor. The decision must be able to be safely made no earlier than when the river reaches about 8.5 m AHD at the Windsor gauge. In terms of prediction confidence levels, the SES insists that the decision making point for Pitt Town will not be earlier than the QPF Limit for Windsor, a river level of about 9.6m AHD. In addition, actual warning and evacuation cannot be required to commence earlier than the Pitt Town QPF limit of around 11.5 m AHD at Windsor Bridge
- SES flood experience derived from actual floods, exercises and planning work indicates that time allowance for decision making, resource mobilisation, warning and evacuation cannot be safely reduced below the currently adopted planning figure of 12 hours minimum
- Because of uncertainty about human behaviour, substantiated by flood experience over recent years, there is no scope for reliably planning to allow less time for flood warning than that estimated for doorknocking. Faster warning methods may produce a bonus on the day but cannot be relied upon at the planning stage
- Upgrading roads and applying better urban subdivision design have the greatest potential to put in place reliable evacuation capacity that can be considered as a safety factor
- Unless expert written advice to the contrary convinces the SES otherwise, the maximum traffic flow rate used in planning (600 veh/hour/lane) should not be increased. The figure of 600 Veh/hr/lane allows for minor traffic problems and driver stress due to unfamiliarity, darkness, heavy rain, and high traffic density. It does not allow for major interruptions to traffic flow such as a road closure due to a serious vehicle accident, a power line or tree falling across the road, for which a safety factor must be added (see A Safety Factor for Traffic Movement, above)
- The following limitation will apply where road widening is used to create a 2-lane road with a trafficable shoulder for inbound emergency service vehicles. When calculating the traffic movement duration, the period of dual lane outbound flow will be restricted to not more than 50% of total traffic volume. In any case, the dual outbound flow must be limited to the capacity of the buffer car park at the convergence point. See Part 6 above, for more detail on this subject
- It is of paramount importance that pressure to increase urban population numbers does not see essential safety factors that may have been achieved at great monetary cost, being converted into additional population growth, increasing flood risk and lowering public safety standards.

7. Application Of Time-Line Analysis to Pitt Town

The SES has been asked to analyse three growth scenarios for Pitt Town. The scenarios have been termed Low Growth, Medium Growth and High Growth and the corresponding dwelling numbers are 485, 730 and 1405. Shown in Figures 1 to 7 below are the results of the application of the time line concept to the analysis of these growth scenarios. A number of assumptions have been factored into the creation of these time lines. These assumptions are:

1. The starting point for measuring elapsed time on the time-line (time zero hours) is based on the point in time when the Hawkesbury River at Windsor Bridge flood gauge will be at a height of around 6mAHD.
2. The 6mAHD figure is the result of studies undertaken both during the production of the Hawkesbury-Nepean Floodplain Management Strategy report in 1997 and the emergency planning work undertaken by the SES, DLWC and RTA since 1997. The studies showed that it is not possible to use a height lower than 6mAHD because there will be no chance of assessing the severity of a developing flood so early in an event. The 6mAHD assumption has been used when investigating options for upgrading existing evacuation routes.
3. The BoM has indicated that in a flood likely to exceed the level of the Pitt Town evacuation route (16 m AHD) the QPF Limit will be around 9 hours before 16 mAHD is reached. This means the QPF limit is approximately equivalent to a height of about 11.5 m AHD if the rate of rise is 0.5 m/hour.
4. For the purpose of assessing critical issues such as future growth, the SES recommends a situation where warning and evacuation can safely takes place above the QPF Limit. Doing so will move these activities into a time period where better flood data will be available and there can be more confidence in the decision to evacuate.
5. In recognition of the above QPF principle, all time lines are drawn with the start of warning and evacuation either on or above the QPF limit i.e warning cannot be required to commence below the QPF Limit.
6. The point on the time-line where a decision has to be made so that there can be enough time to complete a full evacuation of the existing community, is called the Flood Risk Status Quo Line (FRSQL). The performance of growth scenarios or other changes that alter the time frame are expressed relative to the FRSQL.
7. The time base is derived from an assumed average rate of river rise of 0.5m/hour. This rate of rise has been observed in floods analysed using mathematical models 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). Recent work by Sydney Catchment Authority studying extreme rainfall events suggests that short duration, faster rates of rise are thought to be possible, up to 1.5m per hour. This data is currently being independently validated and assessed for the SES and at this time has not been incorporated into the current evacuation analysis.
8. 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 as described in part 6, A Safety Factor for Flood Evacuation Operations, above.

9. The time needed to drive vehicles out is calculated a described in part 6, A Safety Factor for Flood Evacuation Operations above.
10. The minimum time to be set aside for vehicle movement will be 2 hours comprising 1 hour flow time plus a 1 hour safety factor i.e values of less than 1 from the formula V/600 will be rounded up to 1 hour.

Figure 1 Time Line for Existing Population

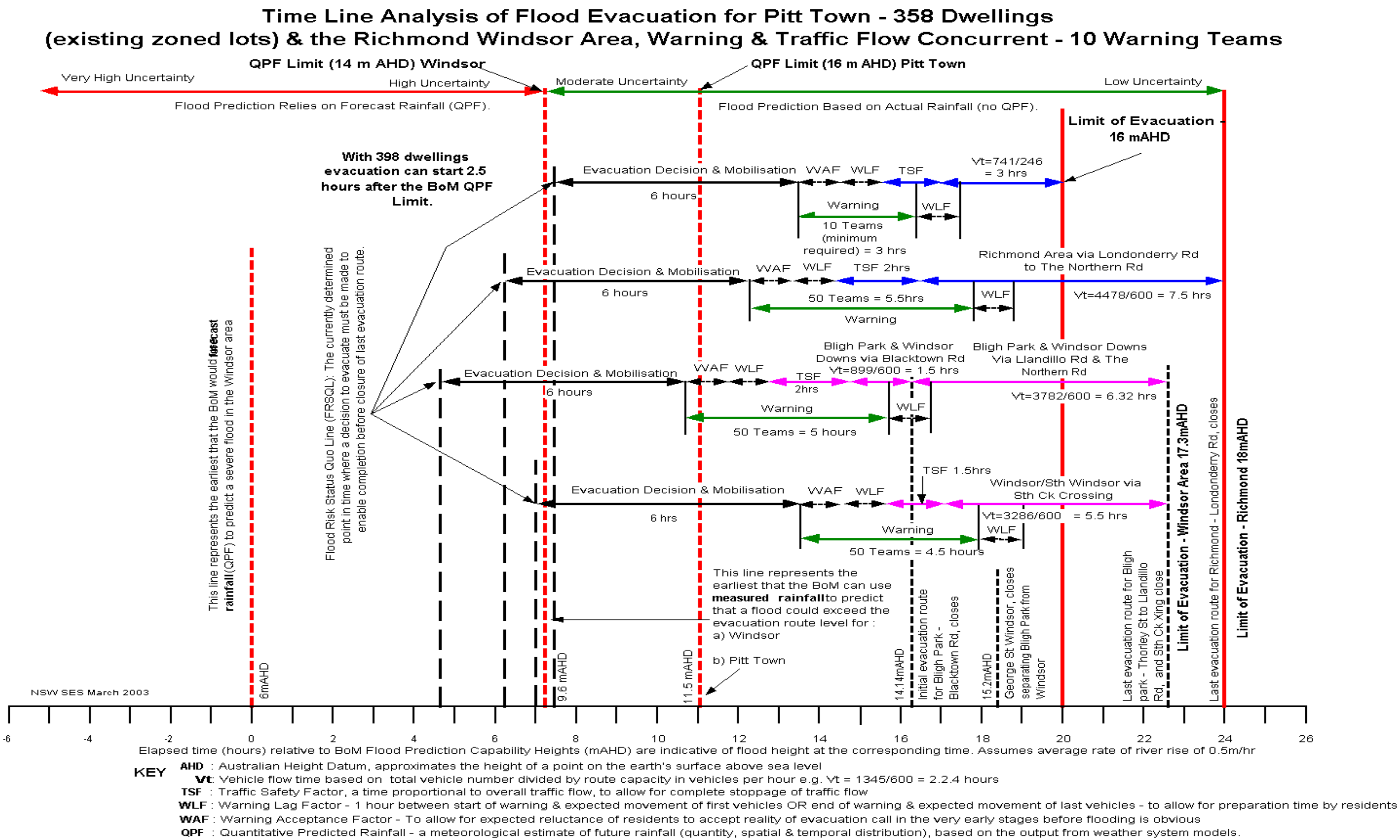
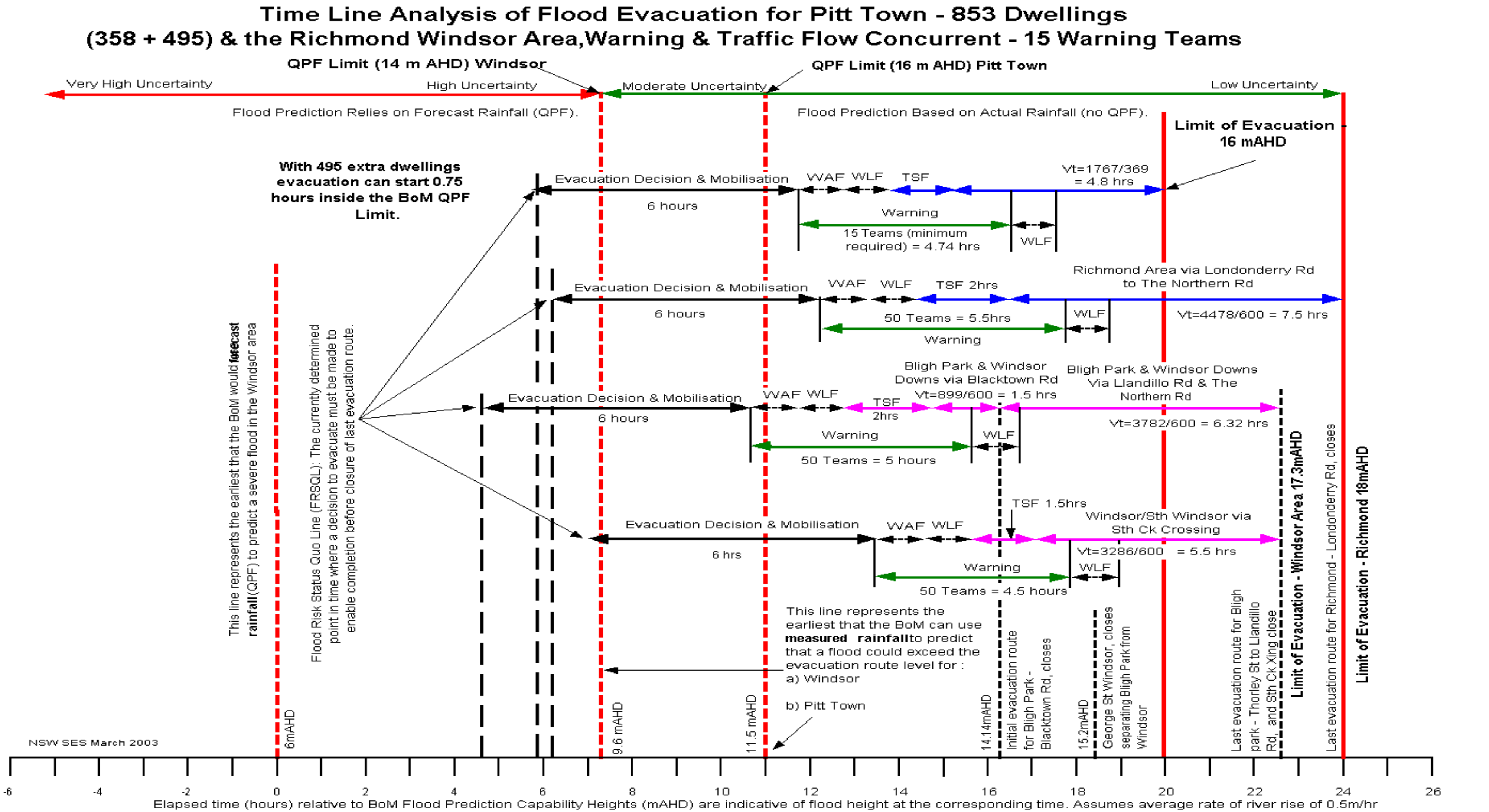


Figure 2 Time Line for Scenario 1



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.

Figure 3 Time Line for Scenario 2

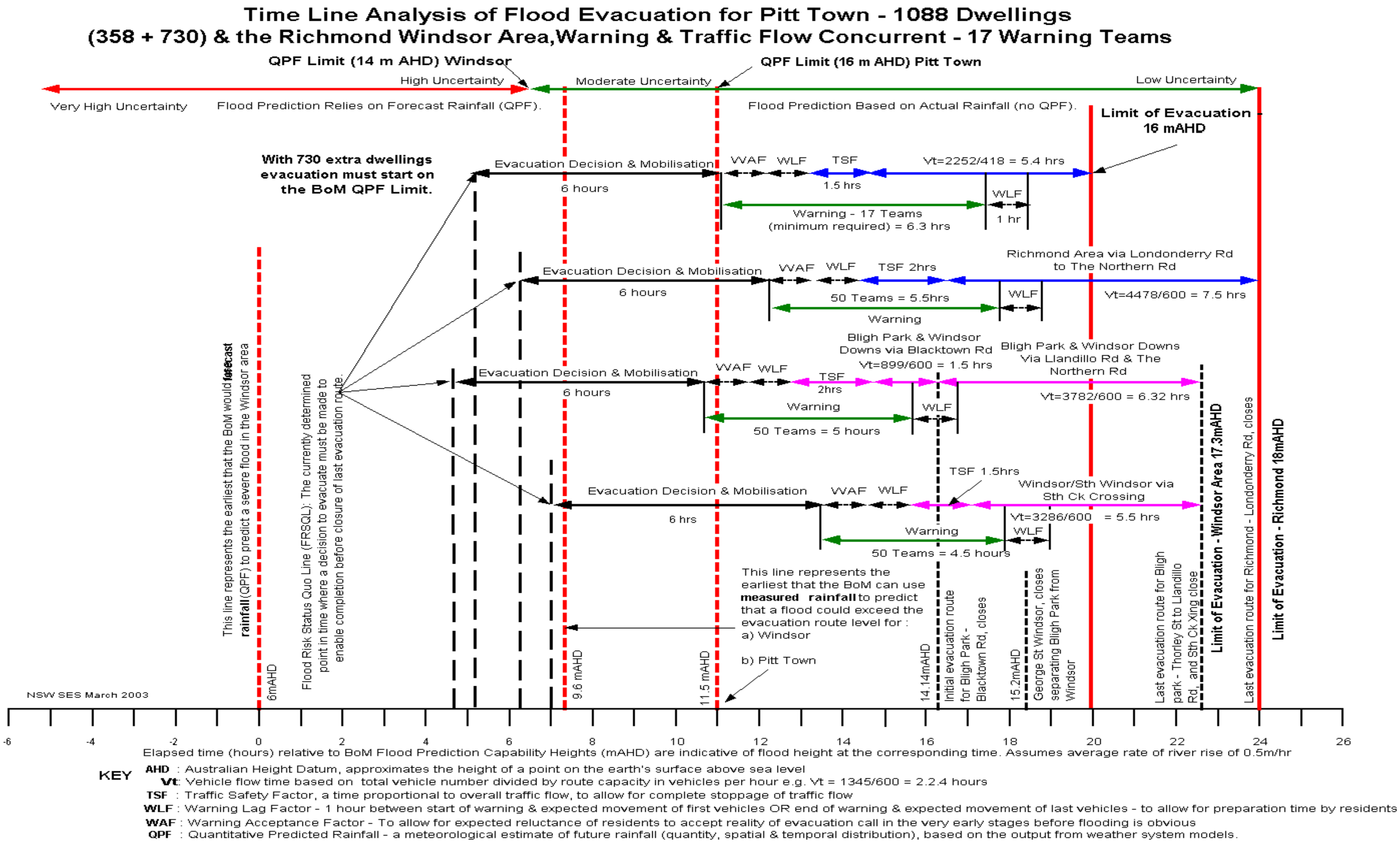


Figure 4 Time Line for Scenario 3

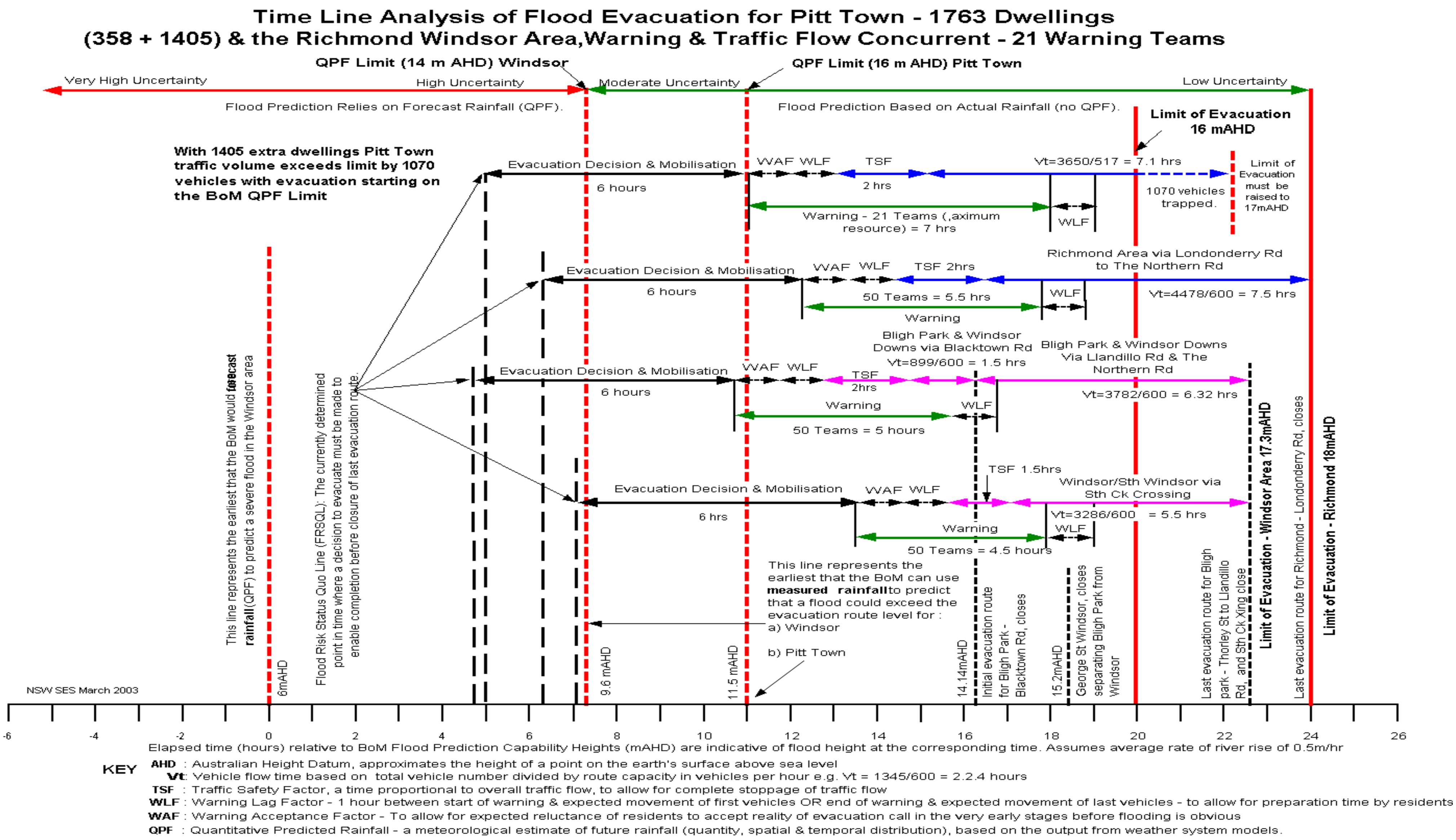


Figure 5 Time Line for Scenario 4

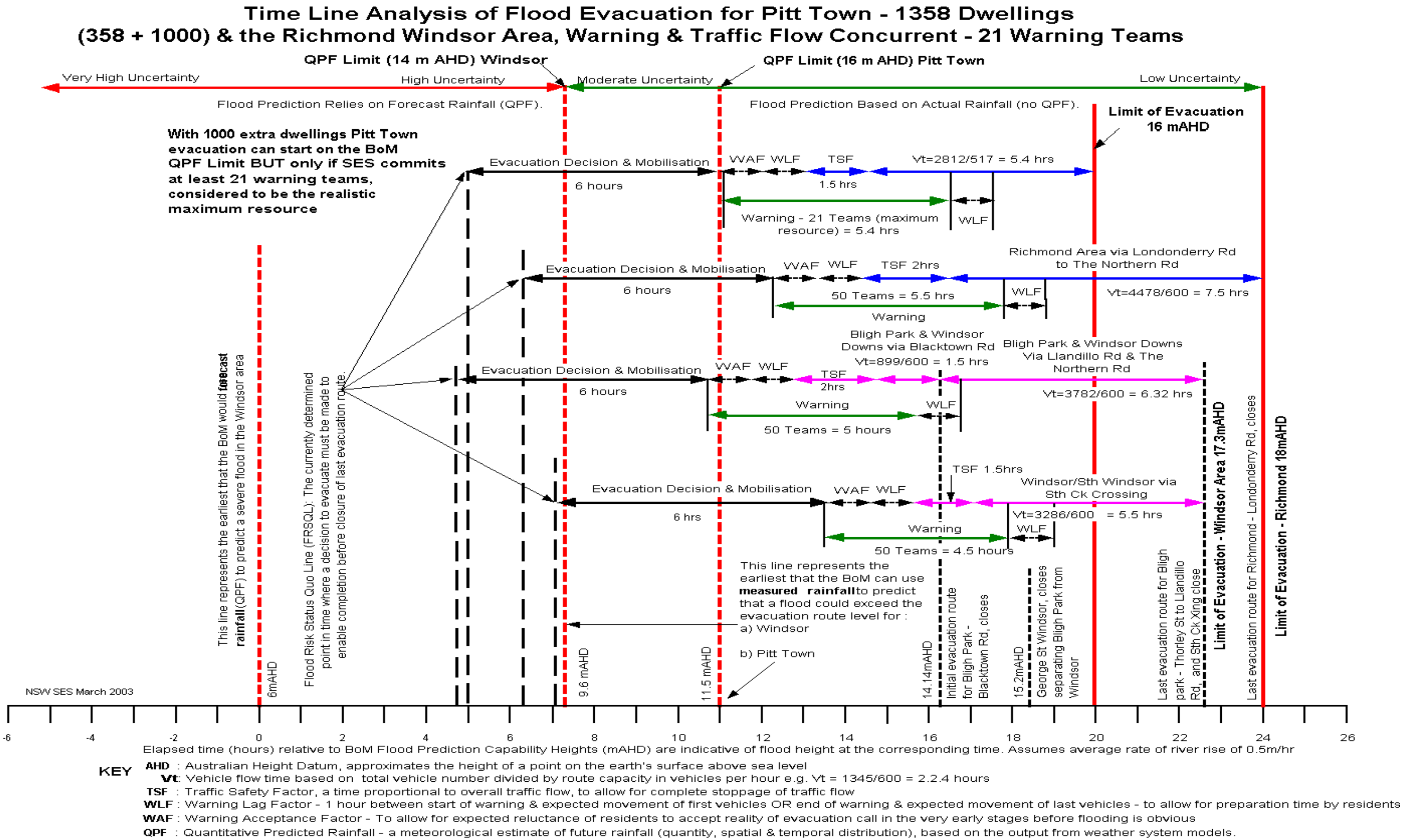


Figure 6 Time Line for Scenario 5

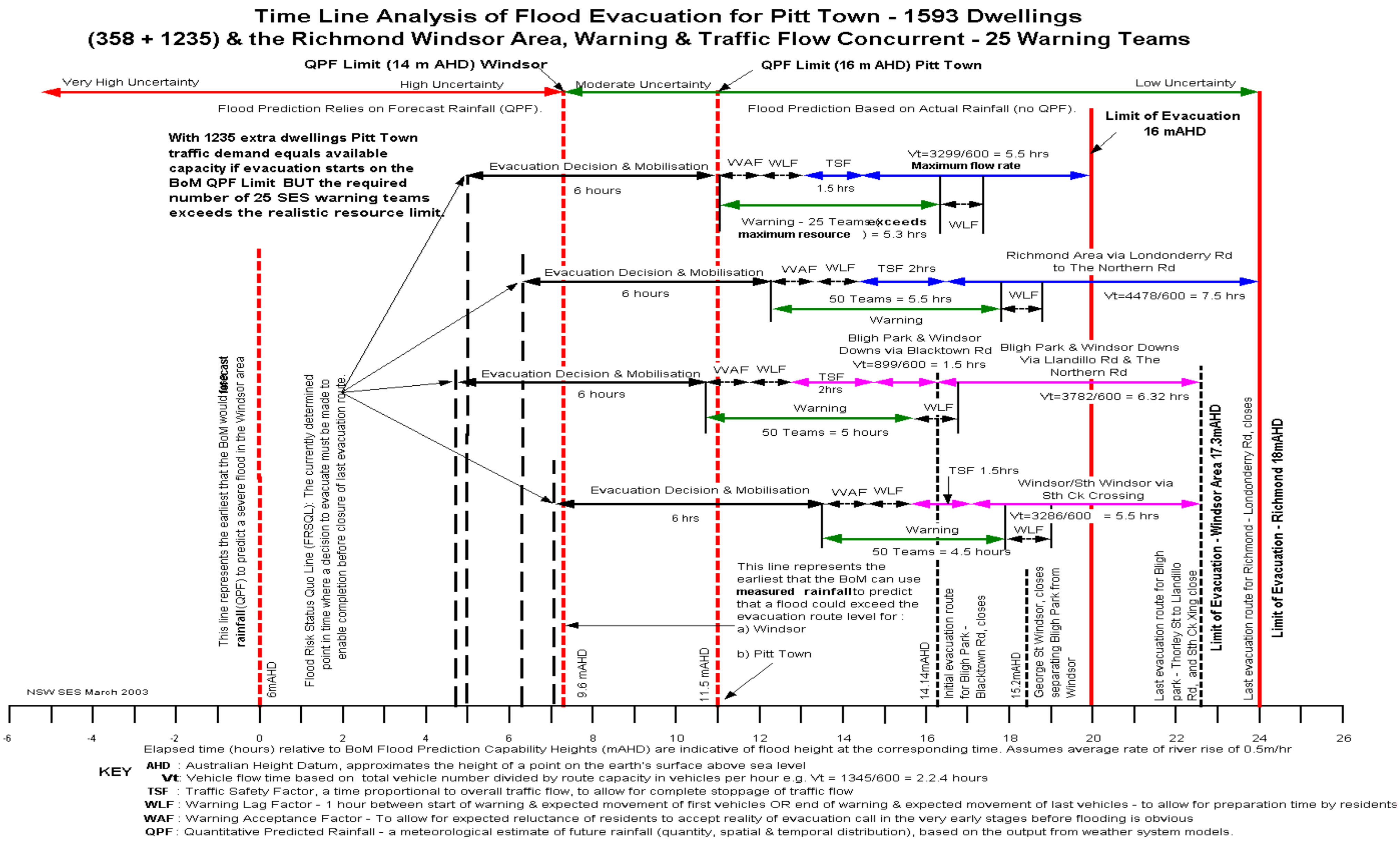
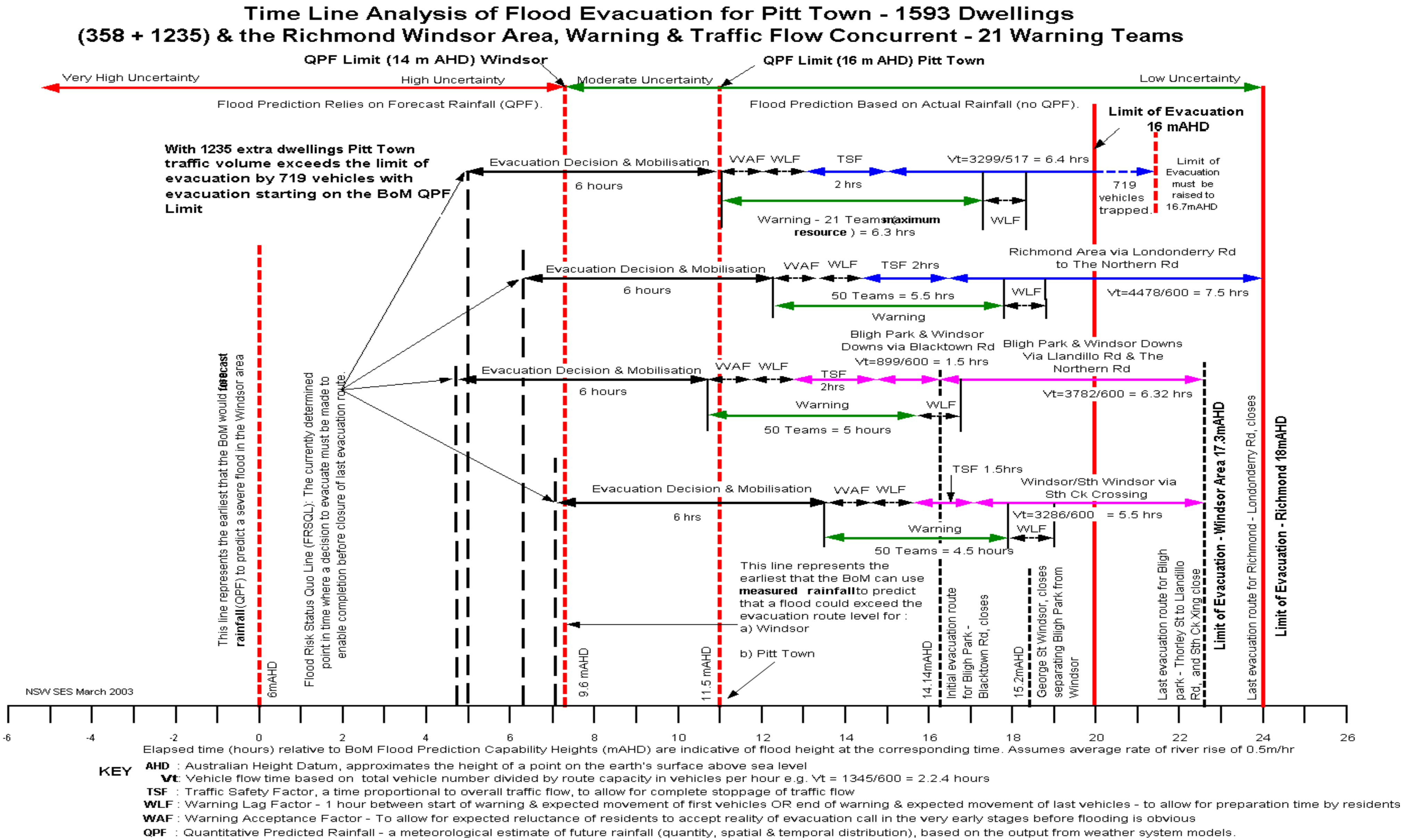


Figure 7 Time Line for Scenario 6



8. Discussion of Time-Line Analysis Results

The time lines shown in figures 1 to 7 reveal that two of the three growth scenarios proposed for the LES, the low (495) and medium (730) scenarios are acceptable without the need for physical upgrading of existing evacuation route capacity. The high growth scenario (1,405) would require physical upgrading of the evacuation route. This is discussed below.

Existing Population (see Figure 1)

This scenario determines the existing public safety level in terms of flood risk. The analysis shows that the evacuation decision must be made when the Hawkesbury River is at a height of around 9.7 mAHD to allow sufficient time to complete a full evacuation of Pitt Town using existing roads. The 9.7 mAHD point is the Flood Risk Status Quo Line (FRSQL) for Pitt Town.

This raises the question - is an FRSQL of 9.7 mAHD acceptable for Pitt Town?

As stated earlier in this report (see Constraints and Opportunities for Creating an Overall Safety Factor, above) the SES insists that the decision making point (FRSQL) for Pitt Town is no earlier than the FRSQL for the area around the Windsor Bridge flood gauge. For the Windsor area the lowest evacuation Route is at 14.14 mAHD, the QPF Limit is at about 9.6 mAHD and the FRSQL is 8.4 m AHD. For the existing Pitt Town population it is possible to make an evacuation decision and mobilise resources at about the time the Windsor area FRSQL is reached but to then wait until about 2.5 hours after the Pitt Town QPF Limit is reached (around 11.5 mAHD) before commencing warning and evacuation.

Considering those factors, an FRSQL at 9.7 mAHD is an acceptable outcome for the existing population in terms of flood emergency risk management.

Scope for Urban Growth

The evacuation of Pitt Town is independent of the evacuation routes used by other areas such as Windsor and Richmond but decision making and mobilisation of emergency service resources will probably be closely linked. The earliest that an evacuation decision would be made for the Windsor area is at height of about 8.4 m AHD at Windsor This is the Windsor area FRSQL. For this reason, provided that warning and evacuation of any future Pitt Town population can take place above the Pitt Town QPF Limit (11.5 m AHD), the post urban growth Pitt Town FRSQL, could be redefined at no lower than 8.4 mAHD without creating an unacceptable risk. As stated above, the SES will not accept that warning and evacuation would need to commence below the Pitt Town QPF Limit. In fact, by allowing for the 6 hours SES evacuation decision and mobilisation prior to 11.5 m AHD, the FRSQL would be at about 8.5 m AHD indicating that 8.5 mAHD is the lowest logical FRSQL.

Growth Scenario 1 – Additional 495 Dwellings (see Figure 2)

Adding 495 new dwellings to Pitt Town will increase the expected number of dwellings to doorknock from around 358 to 853 and the number of vehicles to be moved from around 734 to 1749.

Because the SES would plan to use a larger warning taskforce (15 teams instead of 10) the warning time increases by a factor of 1.6 from 3 hours to 4.7 hours despite more than a doubling (x 2.4) of the scale of the warning task.

Assuming that only the existing roads are used, the time required to move all vehicles out of the area will increase from 4.5 hours to 6.3 hours.

In scenario 1 the evacuation decision would have to be made when the Hawkesbury River reaches a height of around 8.9 mAHD. This is below the current Pitt Town FRSQL but above the Windsor FRSQL and the tasks of warning and vehicular evacuation are both possible above the Pitt Town QPF Limit. This is acceptable to the SES and the decision making point (FRSQL495) does not have to be adjusted back up to 9.7 mAHD.

Growth Scenario 2 – Additional 730 Dwellings (see Figure 3)

Adding 730 new dwellings to Pitt Town will increase the expected number of dwellings to doorknock from around 358 to 1088 and the number of vehicles to be moved from around 741 to 2252.

The SES would plan to use 17 teams and the warning time increases by a factor of 1.8 from 3 hours to 5.3 hours despite the scale of the warning task being tripled.

Assuming that the existing roads are used, the time required to move all vehicles out of the area will increase by a factor of 1.5 from 4.5 hours to 6.9 hours.

The analysis of scenario 2 shows that the evacuation decision must be made when the Hawkesbury River is at a height of around 8.6 mAHD. This is just above the Windsor FRSQL and the tasks of warning and vehicular evacuation are both possible above the Pitt Town QPF Limit. This is acceptable to the SES and the decision making point does not have to be adjusted back up to 9.7 mAHD.

Growth Scenario 3 – Additional 1405 Dwellings (see Figure 4)

Adding 1405 new dwellings to Pitt Town will increase the expected number of dwellings to doorknock from around 358 to 1763 and the number of vehicles to be moved from around 741 to 3650.

The SES would plan to use 21 teams so the warning time is increased by a factor of 2.4 from 3 hours to 7 hours despite the scale of the warning task increasing by a factor of 4.9.

Assuming that only the existing roads are used, the time required to move all vehicles out of the area will double from 4.5 hours to 9 hours.

The analysis of scenario 2 also shows that the evacuation decision must be made when the Hawkesbury River is at a height of around 7.5 mAHD if there is to be sufficient time to complete a full evacuation of Pitt Town before the current evacuation route level of 16 mAHD is reached. This is 2 hours earlier than the Windsor FRSQL of 8.4 mAHD. The warning and evacuation elements must also commence more than one hour before the Pitt Town QPF Limit. This is totally unacceptable to the SES and to enable scenario three to be adopted the decision making point must be adjusted back up to 8.5 mAHD and warning and evacuation must be able to commence at 11.5 mAHD.

To shift the decision making point from 7.5 mAHD up to 8.5 mAHD the evacuation route must be raised so that it closes about 2 hours later than it would at a height of 16 mAHD. This equates to about 1metre of road height. Currently the Pitt Town evacuation route has a low point where the road dips to 16 mAHD and this will need to be raised to 17 mAHD to accommodate scenario 3.

Growth Scenario 4 – Additional 1000 Dwellings (see Figure 5)

This is an additional scenario added by the SES to indicate the upper limit of development potential set by applying the maximum acceptable demand on SES resources (50 personnel) within the constraint of the existing evacuation route. The combination of both these parameters caps development at no more than about 1,000 additional dwellings. The warning and vehicular evacuation process at this development scale fully occupies the available time between the QPF Limit and the closure level of the evacuation route. The decision making and mobilisation can take place at no lower than about 8.5 mAHD, corresponding to the lowest acceptable FRSQL for Pitt Town.

Growth Scenarios 5 & 6 – Additional 1235 Dwellings (see Figure 6 & Figure 7)

These two scenarios are included by the SES to show what the upper limit of development could be if the SES increased available personnel for warning to a level that could fully utilise existing evacuation route capacity i.e 600 veh/hr. This would require 60 or more SES personnel and this is not acceptable. Assuming that no more than 50 SES personnel were available, the evacuation route would have to be raised by about 0.7 of a metre to accommodate the same 1,235 new dwellings.

9. Road Upgrading to Deal With a Time Deficit

Where an evacuation time-line analysis indicates that the time available in a flood is likely to be too short to achieve the required evacuation, extra time has to generated for the whole operation or the entire operation has to be condensed into shorter time frame. As discussed previously in relation to safety factors, this can be achieved by shifting the timing of the event that caps the available time e.g. flooding of a route, or by shortening the duration of one or more of the individual operational elements. Of all the available options, upgrading evacuation routes will create the most reliable and significant improvements.

Using road upgrading works there are only two practical options that can be used – make existing roads last longer in a flood by raising the surface level of roads <u>or</u> increase the traffic flow capacity from the area by providing extra outbound lanes. These options can be used individually or in combination and are discussed below.

Road Raising

This option is the most straight forward in emergency management terms, requires little or no alteration to the SES flood evacuation procedures and is the preferred option from the Service's point of view. From a road engineering viewpoint the option may not be easy. Any existing points on the proposed evacuation route that are at 16mAHD (the current lowest level), must be raised to the required level **and** no other point on the route within the floodplain can then be lower than this new level.

Because of landform, economic and social constraints it may not be possible to achieve road elevations much higher than 16m AHD at any identified low point. This is a serious physical constraint on what is possible in terms of increasing the total time available for all the elements of an evacuation operation.

Additional Outbound Lanes

Providing more traffic lanes so the same number of vehicles can be moved in a shorter time frame could be achieved by either constructing a new independent evacuation route or by widening an existing road to add new lanes. It is important to understand that extra lanes can only be of benefit if sufficient traffic demand can be created by the warning process (see A Limit to Warning Speed and Traffic Flow, above). To achieve the required traffic demand by generating in excess of 600 vehicles per hour will require more than 60 SES personnel, exceeding the capacity of the SES to undertake warning in Pitt Town. Theoretically faster warning methods exist but are not valid in an urban planning context (see Warning, in part 6, above). The options for creating additional lanes are discussed below, largely for the information of readers.

Construction of New Evacuation Routes

Any new routes must be constructed as high as possible relative to flood levels. If they are too low they will be closed by floodwater too soon and this will force evacuation decisions back into the early and uncertain phase of a flood. A new route must also avoid convergence with other evacuation routes, including those from other communities. Convergence will force traffic streams to merge and this will reduce potential traffic flow rates.

New routes at high levels relative to flooding are the preferred option for dealing with a time deficit.

There does not appear to be any prospect of constructing a new independent evacuation route out of Pitt Town so widening the existing route seems to be the only way of increasing outbound traffic capacity.

Widening of Existing Evacuation Routes

The widening option is more complicated and could be achieved in either of two ways:

- A fully defined 3 lane road;
- A 2 lane road with a wide all-weather serviceable shoulder wide enough for emergency vehicles to safely drive in the opposite direction to the outbound flow;.

The first method is the preferred, being easier to manage operationally than the second option.

Ideally the 2 lane outbound flow should extend the full length of the evacuation route from origin to evacuation destination. As a minimum standard, the widening must extend from the main feeder point at the start of the evacuation route to a point beyond the limit of flooding (the PMF) where vehicles can be temporarily stored prior to continuing on a single outbound lane to the final destination such as an evacuation centre.

So that flow can be buffered back down to a single lane, without restricting dual lane flow, a holding car park has to be created outside the PMF extent that allows vehicles to arrive at approximately twice the rate at which they can leave. This buffered flow may have to be managed for several hours.

The dual lane to single lane buffer car park will have to have a capacity of 1200 vehicles for each hour of expected dual lane outbound flow. The figure of 1200 vehicles per hour must be used because this higher flow rate is possible on a rural road. The duration of the vehicle movement element is estimated for a worst case average flow of 600 vehicles per hour as discussed in part 6, A Safety Factor for Flood Evacuation Operations, above.

The preliminary consideration by the SES of this option indicates that road widening will have to extend from Pitt Town to a location such as the village of Scheyville. At Scheyville facilities will have to be available to provide all-weather parking to hold the excess of vehicles arriving.

Limitation of Dual Lane Outbound Flow

The following limitation will apply when a buffered 2 lane flow is used because of the operational complications and the greater possibility of major traffic problems. When calculating the traffic movement duration, the period of dual lane outbound flow will be restricted to not more than 50% of total traffic volume. In any case, the dual outbound flow must be limited to the capacity of the buffer car park at the convergence point

The traffic management associated with dual lane outbound flow, especially if the flow has to be buffered, will require more on the ground resources to manage it and the SES evacuation plans and procedures will have to be modified.

10. References

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