Drivers for Evacuating Vehicles – What are Reasonable Assumptions for Evacuation Modelling?

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Background

In recent years there has been significant progress in the sophistication of modelling software for the simulation of flood evacuations and the evaluation of evacuation route capacities. There has been an evolution from basic empirical models to estimate the difference between the time required and time available for vehicular evacuation (i.e. the NSW SES Timeline Evacuation Model [TEM]) to agent-based models representing individual vehicles as they are warned of and respond to rising floodwaters (i.e. Life Safety Model [LSM]). Sophisticated models are capable of providing dynamic outputs displaying the evacuation routes and fates of individuals and vehicles over time at high spatial and temporal resolutions, and can fully integrate with two-dimensional flood models (Molino et al., 2014).

However, computer models are only as good as their assumptions and input data; if these are not realistic the model outputs could be meaningless. Some key inputs and assumptions required for accurate flood evacuation modelling include:

- The number of evacuating vehicles;
- The origin locations (i.e. from both residential dwelling and non-residential buildings) of vehicles;
- The amount of warning lead time available for areas requiring evacuation;
- Evacuation triggers (i.e. flood gauge levels) for specific areas;
- Time required between evacuation order and departure;
- Road capacity (i.e. how many vehicles can travel per lane per hour under evacuation conditions) and road network;
- How to account for delays from vehicle breakdowns, traffic accidents, fallen trees or other events which can disrupt traffic flow (i.e. Traffic Safety Factor);
- What evacuation routes may be cut by overland, local creek or riverine flooding;
- How to account for non-evacuation traffic which may be using the roads during an evacuation;
- The evacuation destination(s).

This paper offers some insights into the challenges we have found around the first of these inputs: the number of evacuating vehicles.

Our Experience

In recent years Molino Stewart has built large-scale, agent-based flood evacuation models for both the Hawkesbury-Nepean River and Georges River (Molino et al., 2021) floodplains where evacuation routing is complex using LSM. It has also used TEM for scores of small to medium scale scenarios where evacuation routes are more straight forward or for the initial evaluation of evacuation challenges in cities such as Mackay in Queensland.

The complex LSM models' inputs and assumptions have been formulated in consultation with the NSW State Emergency Service (NSW SES), Infrastructure NSW (INSW), Transport for NSW (TfNSW) and Department of Planning and Environment (DPE) to ensure they reflected the latest research and best practices for flood evacuation management in NSW and incorporated future broadscale regional, urban and road planning. Local councils provided up to date local knowledge and other consultants, generally representing the interests of developers, provided constructive criticism of the inputs and assumptions.

While these exercises have identified problematic flood evacuation capacity issues in these floodplains, it has also brought to light several challenges when it comes to determining what scenarios to simulate and assumptions to make about evacuee behaviour.

Vehicle Evacuation Assumptions

The most important of these challenges centred around determining the number of vehicles which would need to be evacuated in both the present and future development scenarios. While other parameters such as road capacity and the number and locations of evacuation destination(s) impacted the end results of the models to a certain extent, modelling of multiple scenarios demonstrated that significant changes to the number of evacuating vehicles resulted in the most substantial changes to the end results. Some of the key issues involved in determining the number of evacuating vehicles for the purposes of evacuation modelling are:

- *How many vehicles will evacuate from dwellings?*
- *How many vehicles will evacuate from businesses?*
- *What is the worst-case vehicle evacuation scenario?*
- *How will vehicle ownership and travel preferences change in the future?*
- *What about the evacuees who don't own vehicles?*

The following discussion offers some insights into these questions and the particular challenges they present when building complex flood evacuation models.

How many vehicles will evacuate from dwellings?

Estimating the number of vehicles currently at residential dwellings is reasonably straightforward. In recent flood modelling work, Molino Stewart used an integration of the flood model data, Australian Bureau of Statistics (ABS) Census data, cadastre data, and Google Maps imagery to estimate the number of dwellings that would need to evacuate in a study area. Each dwelling was assigned the average number of vehicles per dwelling (based on the census rates) for its respective suburb.

Similarly, for any proposed future development, the recent local vehicle ownership rate for the suburb can be applied to estimate the total number of vehicles that might be associated with the development. However, recent development trends in multistorey housing are for the number of parking spaces in the development to be limited as these developments are generally close to public transport and town planners are discouraging high car ownership and usage. Much lower rates of vehicles per dwelling need to be assumed in these cases.

This can become even more complicated because through other work, and personal experience, we are aware that where these residential developments are in close proximity to centres of employment, apartment owners lease their parking spaces to workers who travel to the employment centre by car. Thus, what might be counted as a residential vehicle, in reality should be counted as a non-residential vehicle which, as we will see later, has implications for evacuation traffic numbers. As far as we are aware, there is no data available to quantify this practice.

Based on the advice of the NSW SES, it is usually assumed that all vehicles assigned to an evacuating dwelling would evacuate. This is due to a number of factors, including lack of data on how and if people within a home could share vehicles, and because cars are generally expensive possessions that people would be motivated to move out of the way of rising floodwaters if possible. However, it is noted that census data indicates that on the day of each census between about 5% and 10% of dwellings are vacant, either because there are no current occupants or the occupants are living elsewhere on that particular day (on vacation, staying with friends or relatives, in a second home). Therefore, the assumption that all dwellings evacuate every vehicle may be an overestimate of evacuating residential vehicles which may have a significant impact on results.

How many vehicles will evacuate from businesses?

In consultation with the NSW SES and INSW, recent flood modelling work utilised “Journey to Work” data (Transport for NSW, 2011) to estimate the number of workers who drive themselves to their place of work in specific zones. Unfortunately, similar data is not available for more recent census years.

While this number represents the total number of workers' vehicles which travel to an area, not all of these workers would necessarily be present at their respective worksites at the same time. For example, where a factory has two 12-hour shifts, then only half of the vehicles would actually be there at any one time. There is no realistic way of knowing to what extent counting all of the commuting vehicles is overestimating the number of vehicles in a floodplain at the same time.

What is the worst-case vehicle evacuation scenario?

The NSW SES generally requires evacuation modelling of the "worst-case" scenario, with the logic that if it is possible to evacuate in this scenario, it would be possible to evacuate in any scenario. The challenge comes in determining what is the worst case.

Clearly, calculating the number of vehicles which would need to be evacuated in the probable maximum flood (PMF) represents the worst case from a flood extent point of view. But how many of the vehicles that could be within the PMF extent at some time will actually be there when an evacuation is called?

For example, were evacuation to be called in the middle of the night on a week night, then there would be a high likelihood that most people would be at home and few people would be at work. In such a scenario, modelling the evacuation of all the residential vehicles and no non-residential vehicles is probably close to reality (assuming that all residents evacuate). Conversely, if the evacuation is called in the middle of a working day, most non residential vehicles will be at work and the minimum number of vehicles will be at home. What then is the worst combination of residential and non-residential vehicle numbers?

In recent projects the NSW SES has required modelling the simultaneous evacuation of all residential and non-residential premises in the floodplain. The methodology adopted uses the travel to work data to exclude non-residential vehicles which have originated from the floodplain. The logic of this modelling is that all people will leave work and travel home when an evacuation is called regardless of where they work or live. Those who live and work on the floodplain are being counted in the residential evacuation traffic as are those who live on the floodplain and work outside of the floodplain. Only those who work on the floodplain and live outside of the floodplain are being counted as evacuating non-residential vehicles.

While this process ensures that those who both live and work within the study area are not double counted, it is reasonable to ask whether this represents a realistic scenario. For example, not many businesses operate 24/7, and a business which is open as much as 70 hours per week is unoccupied for nearly 60% of the time. Furthermore, workers may be told not to come to work due to flood risk if their place of work is not yet open when an evacuation is called. This means that there is a significant period of time when no workers would be required to evacuate from their place of work in the event of a flood.

Additionally, drivers leaving their places of work may need less time to commence their evacuation than residents or may leave before an official evacuation order is called simply because that is when they would have left work in any case.

If the evacuation triggers for employment areas are at a lower level than those for the residential areas, or even at the same level, it is highly likely that most non-residential vehicles that have to evacuate would have commenced to do so before many of the residential vehicles are ready to do so. In such a scenario, there may little or no convergence of non-residential and residential traffic.

The other possibility is that the residential areas are told to evacuate first and while they are evacuating it is the end of the work day for non-residential areas that may not need to evacuate until much later in an evolving flood. In this situation, the first of the residential traffic may be converging with all of the non-residential traffic and then later the roads are completely free of non-residential traffic.

Assuming all residential and non-residential vehicles evacuate simultaneously also assumes that everyone who is outside of the floodplain when an evacuation is called will be able to return to their homes within the available warning window and then evacuate from there. In the sort of extreme rainfall that would require large scale evacuation from a major river, it is probable that there would be widespread flooding across the larger area, likely impacting all transportation networks. Therefore, it is likely not all people would be able to reach their home in time to then evacuate from it because their route home is either flooded or otherwise disrupted.

In a city such as Sydney with multiple employment centres, dormitory suburbs, multiple travel modes and a plethora of travel routes it becomes extremely complex to model the relationship and patterns of residential and non-residential vehicles in order to understand how many vehicles would be realistically evacuating from the floodplain. In regional cities and towns where the majority of people live and work in town and there is limited public transport, this can be much easier to model.

The amount of available warning time compared to the amount of time people are away from home for work will also impact the number of non-residential vehicles on the road. For example, in locations where major floods would have a warning lead time of 12 hours, there would be sufficient time to advise workers to not come to their worksite in the floodplain. Similarly, the amount of time it takes for the flood to rise to the PMF level compared to the usual time of absence from a home or place of work would impact the number and type of vehicles on the roads.

While it is important to understand the worst possible case when undertaking analyses with regard to loss of life, particularly when tens of thousands of people are involved, when evacuation consequences are inconvenient rather than fatal (such as long traffic queues), more likely outcomes may be tolerable.

How will vehicle ownership and travel preferences change in the future?

Across the country, vehicle ownership rates have generally been increasing over the past three decades. However, between 2017 and 2020, passenger vehicle ownership slightly decreased across most Australian states and territories before increasing again from the start of the COVID-19 pandemic in 2020 (Australian Infrastructure and Transport Statistics, 2021). It is yet to be seen how this trend will change in the future, and if increasing rates of car ownership will be maintained.

As mentioned earlier, many new apartment complexes, particularly those located close to public transport, are designed to accommodate far less vehicles per dwelling than the current average for the surrounding suburb. Modelling of both present and future evacuation scenarios will also need to account for changes to working arrangements since the start of the COVID-19 pandemic, as data becomes available. The ABS reported that in August 2021, more than 40% of Australians were regularly working from home (ABS, 2021). These emerging and rapidly changing work patterns are difficult to account for in modelling current and future flood evacuations, and there is uncertainty about how this trend will change in the future. It is possible that there will continue to be an overall decrease in the number non-residential vehicles and an increase in residential vehicles at any one time.

With autonomous or self-driving vehicles projected to increase in popularity, particularly within urban areas, early research has investigated their potential use in evacuation scenarios. A recent study modelled evacuation from hurricanes in Texas, USA using autonomous vehicles (AVs) and found that higher numbers of AVs delivered more efficient evacuation performance due to higher evacuation order compliance, lower headways, and higher road capacity. It was also found to reduce overall evacuation costs, network clearance times and uncertainty in travel times (Lee and Kockelman, 2021).

However, the feasibility and timeline of using widespread AVs in evacuation will depend on their technical maturity and penetration. Furthermore, the future ratio of vehicles to people could go in one of two directions, or a hybrid of both, in the future. At one extreme, AVs could become like mobile phones with most people owning a personal one and therefore many more vehicles having to be used to evacuate the same population as now. It is not known whether the increased efficiency of their evacuation rates would offset the increase in their numbers in such a scenario.

At the other end of the scale, AVs could become more like public telephones (or what public telephones were like many decades ago). There will be a fleet of public transport AVs which people only call upon when they have need of them and the fleet size will be something less than peak annual demand. However, in this scenario the evacuation demands may exceed supply, particularly if large parts of the fleet are unable to reach the flood affected area and people may be stranded without vehicle transport.

What about the evacuees who don't own vehicles?

Even under existing and near future development with convention vehicles, it is apparent that there are many areas without access to private vehicles for flood evacuation. Analysis of the number of households without a vehicle in the Georges River and Woronora River floodplains was recently undertaken based on 2016 ABS Census data. This showed that approximately 10% of people within the floodplain do not have a vehicle at home. These people are not distributed evenly across the floodplain; mapping shows that there are clusters of dwellings in areas such as Liverpool, Cabramatta, Fairfield and Campbelltown where more than 30% of dwellings have no vehicle at home (Figure 1).

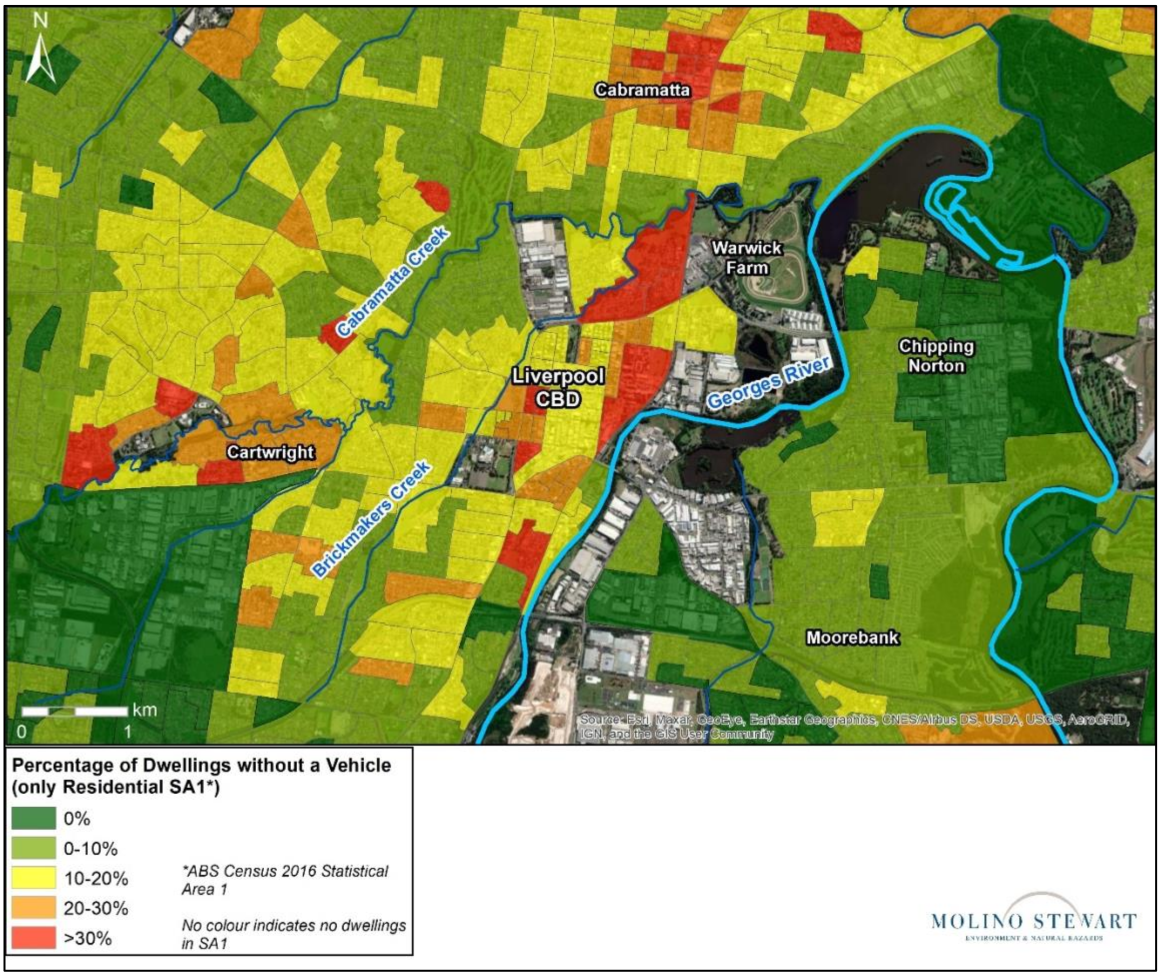

Figure 1. Percentage of dwellings without a vehicle at home in an urbanised part of the Georges River floodplain (ABS, 2016).

These areas appear to fall into two categories. Many are located close to public transport, in local CBDs, where a higher proportion of residents live in multi-storey unit blocks. According to the 2016 census, 21% of Australia's apartment households reported having no motor vehicle.

There are also areas with low vehicle ownership rates concentrated around areas of low income, often in large public housing estates. These estates in particular may present elevated risks because there may be a significant proportion of more vulnerable residents living in single storey dwellings.

It was found that if all residents within the extent of the Georges River and Woronora River PMF needed to evacuate, approximately 7,000 people without a vehicle would require an alternate mode of evacuation. Some of these people may be able to walk short distances in advance of the rising floodwaters along a rising pedestrian evacuation route. Others, particularly in the public housing areas, may have mobility challenges or other disabilities which makes self-directed pedestrian evacuation challenging. Others may not have continually rising pedestrian evacuation routes and evacuating ahead of rising floodwaters may not be an option.

It is recognised that both public transport (i.e. rail and train) and pedestrian evacuation have their limitations and may not be able to be relied upon. For example, in April 2015, Sydney Trains estimated nearly 200 significant incidents to Sydney Trains and NSW Trains, and approximately 585 peak and non-peak services were affected during a 3-day period of storms (Transport for NSW, 2017). For these and other reasons, public transport and pedestrian evacuation are generally not supported by the NSW SES. It is noted that failing to evacuate or deliberately Sheltering in Place in floodplains such as the Georges River is particularly risky considering buildings can be isolated and inaccessible to emergency services for more than 24 hours in the PMF.

Conclusions

While agent-based models have proven their utility in modelling the vehicular evacuation of large floodplains with complex evacuation networks, like any model, their outputs are only as good as their inputs. As can be seen, estimating the number of evacuating vehicles ahead of a flood is not always straight forward, particularly on large floodplains in large metropolitan areas. This highlights the importance of using sensitivity testing to see how changing inputs changes outputs and to examine what might be realistic in a real flood evacuation.

It is also clear that for flood evacuation in large, urbanised catchments, it will be essential to have provisions in place to safely manage the large number of people on the floodplain who do not have access to private motor vehicles, many of whom may have mobility challenges. Such a management plan may also apply in scenarios where evacuees do have a car, but their vehicular evacuation has failed for some reason. In cases where staying in the floodplain and sheltering in place is not an option, alternate modes of evacuation will be required, such as pedestrian evacuation, car sharing, or mass transport.

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