TRANSPORT AND INFRASTRUCTURE COUNCIL

Australian Transport Assessment and Planning Guidelines

04 Flood Resilience Initiatives

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Flood Resilience Initiatives

At a glance

- This guidance covers the assessment of flood resilience initiatives.
- Flooding that causes transport facilities to be closed to traffic can give rise to a range of costs for transport users, transport agencies and sometimes for the community more broadly.
- The principal costs to users consist of: waiting for facilities to be re-opened; diverting around closures; use of alternatives transport modes; trip cancellation; and accommodation costs.
- For transport agencies, the principal cost is damage repair after flooding.
- This guidance describes approaches to estimating these costs in the base and project cases.
- Some impacts of facility closure are not readily monetised. Examples are discussed.

1. Introduction

This part of the Guidelines considers the appraisal of flood resilience initiatives in transport. Such initiatives are also referred to elsewhere by the terms flood immunity initiatives and flood mitigation initiatives, as they relate to transport.

Its primary purpose is to illustrate how the ATAP assessment model can be applied to flood resilience transport initiatives. In doing so, it aims to assist practitioners required to undertake assessments of such initiatives.

The impact on flooding is most frequently reported in relation to roads, and the associated road closures. However, flooding can also affect other transport mode (rail, airports, cycling and walking). It can also affect both people transport and freight transport. The guidance here is therefore generic rather than being mode-specific, or specific to traffic type. It can be applied in any modal, multi-modal or trip type situation. The discussion elaborates across various situations. The examples given here relate to roads. Examples across other modes can be added in future as relevant data is obtained.

Flood resilience initiatives aim to reduce the impacts of flooding on transport facilities and services, transport users and transport agencies. Flood resilience initiatives could include:

- Raising or replacing bridges
- Raising pavements, tracks or paths
- Re-building roads, tracks or paths on a new alignment.

Sometimes, the same rain event can cause flooding at multiple sites along a corridor, route or link. Where this is the case, there will be interdependence between flood initiatives. Such interdependent initiatives must be appraised as a package of initiatives. Other than for localised trips, reducing flooding risk at any one site will produce benefits only if all sites on the link are suitably upgraded.

Flood resilience initiatives can be difficult to appraise because of a lack of data describing how users respond to flooding-induced closures. Often appraisers will need to make assumptions about user behaviour. Those assumptions should be made clear in the appraisal report. Where flood resilience benefits are a large proportion of total initiative benefits, sensitivity testing of alternative behavioural assumptions are desirable.

Users of this part of the Guidelines should familiarise themselves with the following related ATAP Guidance:

- Part F3: Options generation and assessment, Chapter 3
- Part T2: Cost–benefit analysis.

Chapter 2 provides an overview, reminding the reader of the ATAP assessment model and its applicability here, listing benefits of flood resilience initiatives (monetised and non-monetised) and discussing some uncertainties in benefit estimation.

Chapter 3 discusses in more detail the various monetised benefits of flood resilience initiatives and illustrates their calculation. It discusses a road immunity improvement as a specific example of a resilience initiative.

Chapter 4 provides a discussion of some non-monetised or difficult to monetise benefits.

Chapter 5 suggests some areas for future research.

2. Overview

2.1 The ATAP assessment model

The ATAP assessment model outlined in Section 3.3 in ATAP Part F3 provides the basis for assessing all initiatives, including flood resilience initiatives. The model consists of:

- Clarification of relevant jurisdictional goals, transport system objectives and targets – It is important to be clear about which of these relate to flood resilience from early in an assessment
- Consideration of strategic merit / alignment – The degree of strategic alignment of flood resilience
- Use of cost–benefit (CBA) and the Appraisal Summary Table (AST). The AST provides the mechanism for presenting all the appraisal results—monetised and non-monetised—in a single location

  The ATAP appraisal methodology recognises that all benefits and costs—monetised and non-monetised—are relevant to the appraisal of initiatives. It facilitates this through use of the AST, in which monetised and non-monetised benefits and costs are presented side-by-side

  The AST also includes quantitative and qualitative impact descriptions—these are necessary inputs to calculating monetised and non-monetised benefits, costs and impacts. Presentation of these inputs can also be of assistance to the decision-maker. Non-monetised impacts that are non-quantifiable can only be described in qualitative terms
- Bringing together all aspects of the assessment into a Business Case (see ATAP Part F4).

2.2 Benefits of improving flood resilience

The benefits of improved flood resilience are classified according to cost reductions to: transport users; transport agencies; and external parties.

2.2.1 Monetised benefits

This paper largely addresses monetised benefits[1] of improving flood resilience which include changes in:

- User costs of flooding:
  - Waiting time for facilities to re-open (includes dry-back period for heavy vehicles)
  - Use of diversion routes, including travel time and vehicle operating costs
  - The costs of trip postponement or cancellation
  - Use of alternative modes of transport such as air transport
  - Injury or loss of life of those attempting to traverse flooded infrastructure

[1] Flood-induced property damage costs could be affected (increased or decreased) by flood resilience initiatives from time to time, but changes in property damages are more likely to arise from broader flood resilience initiatives such as levees and dams. This is a very specialised area of economic analysis that is outside the scope of these guidelines, but interested readers could refer to BTRE (2002) and NRM (2002).

  - Accommodation costs.
- User costs associated with 'normal' (dry weather) operation[2]
- Agency costs:
  - Saturation of pavements, embankments, tracks and paths
  - Washaways of pavements, tracks, paths and tracks, including cleanup costs
  - Damage to bridges and culverts including embankments, including cleanup costs.

As explained in ATAP Part T2:

- Costs are calculated separately for the base and project cases
- Benefits are equal to the incremental difference between base case costs and project case costs.

2.2.2 Non-monetised or difficult to monetise benefits

Facility closures caused by flooding can give rise to a range of costs that are quite difficult to estimate either because of the complexity of flood events or because the data sources and the range of impacts are diffused across potentially large areas of impact. Such costs, and hence benefits of flood resilience, can include:

- Loss of perishable goods
- Loss of access to essential services
- Changes in emergency services costs
- Excess inventory costs.

The above list is not exhaustive but provides an indication of the possible cost reductions likely to occur from improved flood resilience. See section 3 for further discussion.

2.3 Uncertainty in estimating benefits

Estimation of the benefits of flood resilience upgrades is characterised by an abnormally high degree of uncertainty for the following reasons:

- Users have inadequate information about the expected duration of closures due to flooding. What might be a reasonable course of action when viewed in retrospect – whether to postpone a trip, wait at a flood site or take an alternative route - might not be obvious at the time because users lack information about how long a facility or service will be closed and whether alternative routes are likely to be closed as well

[2] Flood resilience initiatives may contain elements that affect user costs when the subject facility is not flooded. For example, a road flood resilience initiative may be a new bridge with wider approaches and smoother surface than in the base case. These features create benefits for users in normal (dry weather) conditions. For road cases, these benefits can be estimated using the parameter values in ATAP PV2.

- Typically analysts will only have link-based trip making data (that is, AADT, traffic composition, the length of the closed section and the length of available diverting routes). Complete accounting for the benefits of avoiding trip postponement and trip diversion is only possible with trip origin-destination information
- Flooding can be the consequence of weather events that affect whole networks simultaneously or as a rolling event. Examples include cyclones in northern Australia and east coast lows that can bring high levels of rainfall along much of the eastern seaboard. During these weather events, users are more likely not to travel because of the uncertainties about closures and other weather-related risks. On the other hand, users who are travelling at the time a flood event unfolds may be trapped on flooded facilities for long periods of time
- Benefit estimation relies on hydrological analysis to determine the average annual time of closure. That information will not be available for all sites that are subject to flooding.
- Some hydrological analyses incorporate consideration of climate change, sometimes via scenario testing. Bearing in mind that the horizon for climate change will tend to be longer than the normal 30 year analysis period for initiatives, appraisers will need to judge the extent to which climate change scenarios warrant consideration by reference to both the average annual time of closure (AATOC) and the annual duration of closure (ADC). If for example the climate change scenario is for AATOC to increase by 1 hour to 25 hours, it might not be worth consideration. However a doubling (for example) of the ADC from 4 hours to 8 hours due to increased severity of rain events with climate change would be worth considering depending on the probability that the hydrologist attaches to the climate change scenario.

3. Estimating monetised benefits

Users whose route is closed by flooding are generally faced with three (safe) options:

- Wait at the flood site
- Divert via an alternative route
- Postpone their trip.
- The use of other available modes of transport – although this is less likely. For example, consider flooding road closures. For non-emergency trips, air transport is an option for those trips that have not commenced when the road closure occurs. Air transport will be option for emergency trips but because medical evacuations and drops of essentials (water, food and medical supplies) are rare relative to normal road-based trip making volumes the diversion costs would generally not be worth estimating.

Each of these options incurs different costs, which become benefits of a flood resilience initiative.

3.1 Estimating user benefits

User costs associated with flooding-induced closures will be lower when diverting routes of suitable quality are available (e.g. suitable surface width, passenger type, strength, roughness, alignment) provided the additional travel time on the diverting route is shorter than the average annual time of closure (AATOC).

Major benefit categories typically estimated in appraisals are:

- Changes in costs associated with waiting at the flood site
- Changes in the cost of diverting around the flooded location including travel time, vehicle operating costs, fares and any other costs involved
- Changes in costs associated with trip postponement or cancellation
- 'Normal' (dry weather) benefits associated with the capacity and surface improvements that may be included in a flood resilience initiative[3]

Flood resilience improvements may reduce but not entirely eliminate these costs.

[3] Note that in estimating dry weather user costs the base case and project case expansion factors need to be expressed as net of the AATOC. For example if the base case AATOC is 1 day, the base case dry weather expansion factor is 364 (365 – 1 days). If the project case AATOC is 0.5 days, the project case dry weather expansion factor is 364.5 (365 – 0.5 days).

3.1.1 Waiting time for facility to re-open

Waiting time is time spent waiting at a flood site for a facility to re-open while not engaging in any alternative activity. Cost per hour of waiting could be estimated using the standard values of time stated in ATAP PV2. Waiting time generally does not increase proportionately with closure times as more users can be expected to elect not to travel or travel to their destination via an alternative route as the time of closure lengthens. Closure times can vary for different vehicle types. Restrictions may be placed on heavy vehicles until the surface has sufficiently dried and the strength of the surface has returned. This is known as the dry-back period.

Average annual time of closure and average duration of closure

Two variables are critical in the estimation of benefits associated with waiting time at flood sites (and in estimation of benefits of reduced diversion costs):

- The average annual time of closure (AATOC)
- The average duration of closure (ADC).

The method for calculating AATOC is set out in Austroads (2013); see also Weeks (2012). The AATOC is calculated between the lowest flood height that causes a facility to be untrafficable and the height of the probable maximum flood (PMF).

AATOC is the average number of hours a facility is closed per year (TMR, 2011). AATOC is calculated as the expected value of the probability distribution of flood closure times.

The average duration of closure (ADC) is the average number of hours a facility is closed per flood event. The ADC is calculated using the following formula:

$$ADC = Total\ Hours\ Closed\ annually\ /\ Number\ of\ Flood\ Events\ annually$$

In general terms, the longer the ADC, the greater the likelihood that users will divert around the closure site or postpone their trip. The longer the practicable diversion route, the more likely it is that users will postpone their trip or wait at the flood closure site. Unfortunately, little if any research information is available to support the assumptions that appraisers will need to make about the proportions of users who postpone their trip, wait at or divert around a closure site. Anecdotal information from local police and emergency services personnel or local media reports may assist but if relied on should be appropriately qualified in the appraisal report.

Waiting time benefit estimation

If for example the ADC equals 16 hours, a relatively high proportion of users could be expected to postpone their trip or find an alternative route should one be available. On the other hand with an ADC of 2 hours, most users could be expected to wait at the flood site for the facility to reopen unless the additional diversion distance was relatively short.

Consider as an example a road closure, with three user types: private car, commercial car and heavy vehicle road users. There is an even rate of vehicle arrivals at the closure site. The assumptions applied in the example are as follows:

Table 1 Inputs to estimation of waiting time benefits (road example)

	Base case	Project case
% of road users at a road closure who: • Wait • Divert • Not travel/ postpone trip	 15% 80% 5%	 15% 80% 5%
AATOC	8 hours	4 hours
Value of travel time: • Private cars • Commercial cars • Heavy vehicles	$/vehicle hr 2013 $25.48 $63.22 $48.17	$/vehicle hr 2013 $25.48 $63.22 $48.17
Average annual daily traffic • Private cars • Commercial cars • Heavy vehicles (Note)	 1000 500 300	 1000 500 300
Route length	150 km (diversion route)	100 km (normal route)
Net diversion distance		50 km

Notes:

1. *Value of time source is ATAP Part PV2*
2. *Using* 6 axle semi-trailers as an example.

In this example, the base case annual cost of waiting for private vehicles is as follows:

Waiting cost year = 1 000 vehicles * 15% *8 hrs AATOC * 8 hrs/24 hrs * $25.48/hr * 0.5

= $5 096

Because the net diversion distance is only 50 km, it is reasonable to assume that only a small proportion of users will choose to wait at the flood site.

With an AATOC of 8 hours, one-third of a day's traffic would be affected by the closure (i.e. 8 hours/24 hours). The factor of 0.5 reflects the even rate of arrival of vehicles at the flood site, i.e. the vehicle that arrives at the flood site at the instant the road is closed experiences the full closure delay; the vehicle that arrives at the instant the road is reopened experiences no delay. This adjustment factor assumes an even rate of arrivals over the period of the closure.

Similar calculations apply for the other vehicle types and for the project case. Note however that with reduced closure times in the project case, the ADC is likely to be lower, which will influence assumptions about user behaviour. If for example closure time reduced from 8 hours in our example to 1 hour, most if not all users could be expected to wait at the flood site rather than divert or postpone their trip.

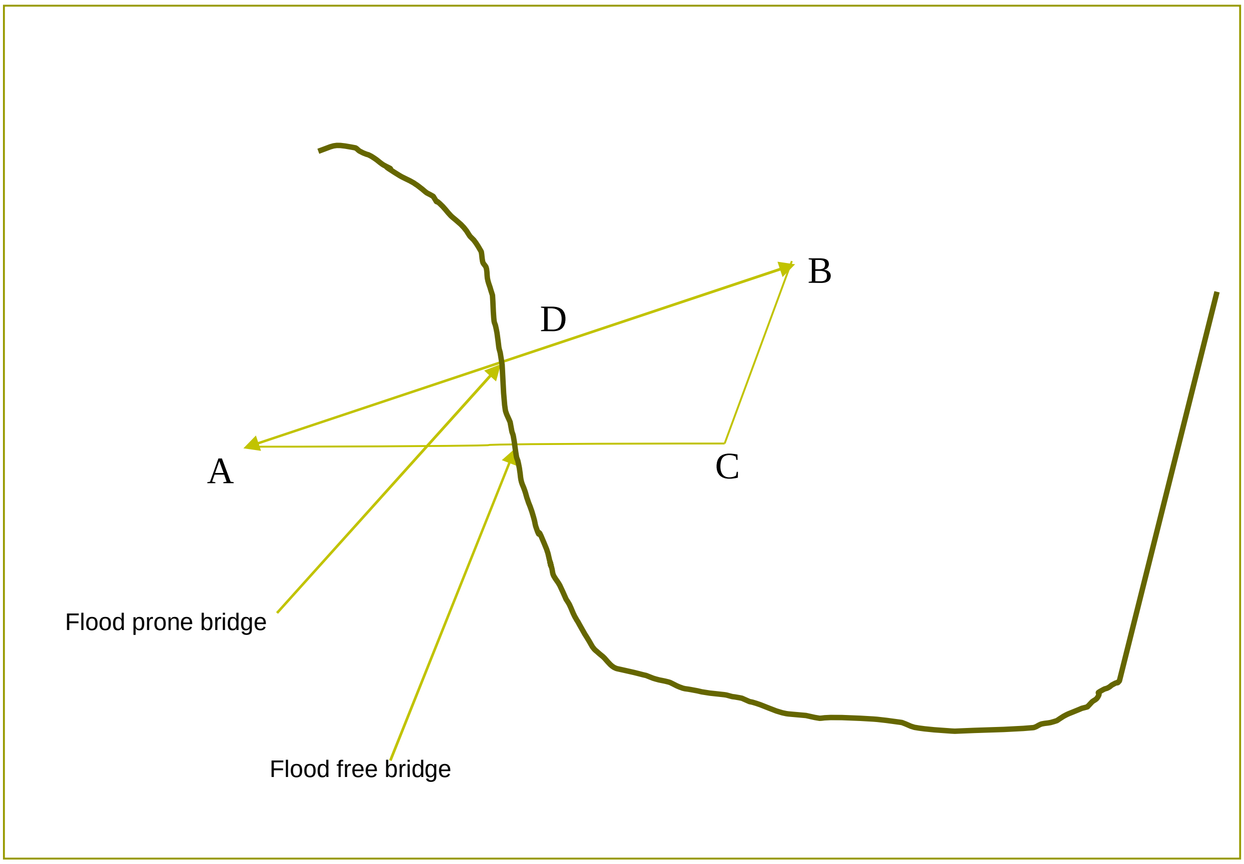
3.1.2 Trips diverting around a closed facility

Diverting trips are those that use an alternative route when a flood closure occurs. If the diverting route around a flood closure site is short, trip origin-destination information will not be needed. If the expected flood closure period is protracted and the diverting route perhaps hundreds of km in length, origin-destination information will need to be sought or inferred.

Take for example a heavy vehicle trip between Melbourne and Brisbane. If truck drivers had sufficient warning of a flooded road closure at Goondiwindi on the NSW/QLD border they could take a diverting route from Moree about an hour south of Goondiwindi, via the Gwydir and New England Highways to Brisbane. The net diversion distance would be approximately 90 km. On the other hand if truck drivers did not get sufficient warning, they could divert just south of Goondiwindi, taking the Bruxner and New England Highways to Brisbane. The net diversion distance would then be approximately 170 km, an additional 80 km.

Sometimes, the diverted trips will need to travel a lot further and may include some backtracking, as illustrated in the mud-map in Figure 1. The letters A, B, C and D denote specific towns. A flood prone bridge exists near D and a flood free bridge is available downstream. Consider trips from origin A to destinations B and D. The normal dry weather route is along route AB and the diverting route is through town C. For trips between A and D, the diverting route would be ACBD, including backtracking between B and D. Where information is available about backtracking trips it should be used but, more likely than not, the information will not be available.

Figure 1 Diverting route



Diverting route costs are a combination of travel time costs, vehicle operating costs, fares and any other costs involved.

Continuing with the example presented in Table 1, further information is presented in Table 2:

Table 2 Inputs to estimation of diverting trip benefits (heavy vehicles)

	Base case	Project case
Route length	150 km (diversion route)	100 km (normal route)
Net diversion distance		50 km
Average speed	80 km/h	80 km/h
Vehicle operating cost (VOC) (Note)	$1.30/km	$1.30/km
Value of travel time (heavy vehicles) (Note)	$48.17	$48.17

Note: See notes for table 1.

The diverting route cost for heavy vehicles in the base case (BC) is therefore:

Diverting route VOC/year$_{BC}$ = 300 vehicles*80%*8hrs/24hrs*150km*$1.30/km

= $15 600

Diverting route travel time cost/year$_{BC}$ = 300 vehicles*80%*8hrs/24hrs*150km/80 km per hr*$48.17

= $7 225

The longer the diverting route, the more likely that the diverting route will contain segments that are not homogenous in terms of route and traffic characteristics. Where this is the case, broadly similar segments could be averaged to reduce the computational demands (see ATAP PV2 for parameter values).

Reductions in diversion distances and kilometres of travel will also reduce crash and environmental costs. Once the annual savings in vehicle kilometres of travel have been estimated, crash and environmental benefits can be estimated using parameter values in ATAP PV2 and PV5.

In our example the net diversion distance is 50 km (the difference between the lengths of the diverting route and the normal route). In reality, diversion distances could range between several kilometres and hundreds of kilometres.

Cycling

Diversion is usually more problematic for cycling trips. There are often less alternative options available for people on bicycles as it can be much more difficult to travel a longer way around the flood location. Detours may often include obstacles (such as stairs or hills) that can be difficult for more diverse bicycle riders such as elderly and those with larger cargo bicycles to navigate.

3.1.3 Trips cancelled or postponed

Users postpone their trip until a flood closure clears because they believe (based on the information available to them) that not travelling is more productive or less costly than the alternatives. Without behavioural information it is impossible to know the proportion of ‘not travelling’ users who can find a similarly productive replacement activity and those who cannot. For someone prevented by facility closure from attending a special event (such as a family wedding or a once-off international sporting event or concert), finding an equally valued replacement activity would be difficult. A simplifying assumption is that ‘not travelling’ users are evenly distributed between the two extremes of:

- Not having an alternative equally valued activity, in which case they incur the full cost of waiting, and
- Being able to undertake an equally valued activity until flood waters clear, in which case they incur no waiting cost.

For users who cannot find an alternative and equally valued substitute activity, the cost of trip postponement (in the base case or the project case) could be approximated as the time of closure multiplied by the relevant value of time according to trip purpose.

Returning to the example in section 2.1.1 in which 5% of users are assumed to postpone their trip, the base case cost of trip cancellation/postponement for commercial car users would be as follows:

Trip cancellation/postponement cost_{BC} = 500 vehicles * 0.05 * 8 hours/24 hours * 8 hours * $63.22/hr * 0.5

= $2 107.

Similar calculations are carried out for the project case except but possibly with differences in the proportion of trips cancelled/postponed and in the AATOC.

3.1.4 Use of alternative modes of transport such as air transport

Excluding emergency services uses, air transport as an alternative to road travel will be an efficient option only in extreme events, for travellers who have ready access to an airport and for travellers who have not commenced their trip by road. Analysis of this option is unlikely to be worthwhile.

3.1.5 Accommodation costs

Sometimes users will need to wait out a facility closure. This will involve two costs: waiting time (see section 3.1.1); and commercial accommodation such as a hotel or motel room, apartment, cabin or caravan parking site.

If data is available from previous events about the numbers of users affected and their distribution between different types of accommodation, costs can be calculated as follows:

$$Accommodation\ cost = Closure\ nights * Rooms\ occupied/night * \$/\ room\ night$$

Note that in estimating the number of room nights, unit nights or site nights attributable to flooding, allowance will need to be made for average room/unit/site occupancy rates (persons per room/unit/site). Occupancy information should be available from commonwealth or state tourism agencies or from Australia Bureau of Statistics visitor accommodation collections.

Accommodation costs are applicable only when flooding causes a net increase in accommodation costs. For users on a fixed duration holiday, extra nights in a flood affected town are more likely to be offset by fewer nights spent in other towns. On the other hand, some users will be forced to stay in commercial accommodation rather than at home or in a hotel/motel rather than at a caravan park site. In those instances the incremental accommodation costs attributable to the facility closure should be calculated for the base and project cases.

It is very likely that appraisers won't have the advantage of behavioural information other than anecdotal observations of local police, emergency services, local government or commercial accommodation owners. Where this is the case, sensitivity testing of alternative assumptions would be desirable.

Flood events, particularly large ones will produce a range of circumstances, including ones in which users backtrack to find accommodation or become trapped by the side of the facility unable to find accommodation. Appraisers need to use judgement in interpreting what user behaviour information is available, but any assumptions made should be described in the appraisal report.

3.2 Injury or loss of life at flooded roads

According to Coates (1999), approximately 2 213 people have died in Australia as a consequence of flooding since 1788 of which 63% have been vehicle related. The average number of vehicle fatalities due to flooding would therefore be around seven per year. Peden and Quieroga (2014) reported that in the ten years to 2012 there were 125 reported drowning deaths in Australian rivers, creeks and streams of which 54% (68) were vehicle related, equal to around 7 per year.

In the ten years to 2011 there were 12 920 road fatalities in Australia, on average around 1,300 per year (see BITRE 2018). Flooding-related road deaths are therefore equal to approximately 0.5% of all road fatalities.

Relative to the size of the road toll, the number of flood-related fatalities is small and likely to be widely dispersed. A further complication is that low probability, higher impact events are more likely to produce washaways incidents and fast moving streams in river valleys will be more dangerous than slow moving floodplain inundation. Quantification of the impacts and monetisation of these benefits is unlikely to be worthwhile unless the flood site is a known blackspot for washaway-related injuries or fatalities. Otherwise this category of benefit is best treated qualitatively in the appraisal report.

3.3 Cost reductions to transport agencies

Flooding events can cause a variety of damage to existing infrastructure ranging from washing away of surfaces to the collapsing of bridges. Repairs to infrastructure can be costly and disruptive. Upgraded infrastructure that is stronger or raised above likely flood levels can reduce these impacts.

Calculating cost reductions to transport agencies

In this section we use the example of improving the flood immunity of a road to illustrate improved resilience. A simple method of estimating agency cost savings attributable to improved flood immunity is to first calculate agency costs for a range of flood severities at a given site (see NRM 2002).

We start with some definitions:

ARI (annual recurrence interval – years) – is the average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration (Bureau of Meteorology, 2010)

AEP (annual exceedance probability) – is the probability that a given rainfall total accumulated over a given duration will be exceeded in any one year (Bureau of Meteorology, 2010). Engineers Australia (2015) defines AEP as ‘the likelihood of at least one occurrence of a given size or larger in any one year. This is usually expressed as a percentage.’ AEP is calculated using the following formula:

$$AEP = 1 - \exp(-1\ /ARI)$$

The stronger a rainfall event, the longer the ARI, and the lower the AEP.

PMF – is the probable maximum flood. Note that PMF has an AEP approaching zero.

Table 3 shows the road repair costs at a given site for floods of different size, as measured by AEP, ranging between:

- AEP 0.2 – approximately a one in five year flood (AEP = 1 – exp-1/5 ≈ 0.2), and
- AEP =0.0001 – approximately a one in 10,000 year flood: an 'ultimate' event (AEP = 1 – exp-1/10000 ≈ 0.0001).

The road in this example has an 'immunity' of AEP 0.2, meaning that:

- The road is immune to flooding for events more frequent than AEP 0.2 (i.e. higher AEP)
- The road will be inundated by events less frequent than AEP 0.2 (i.e. lower AEP).

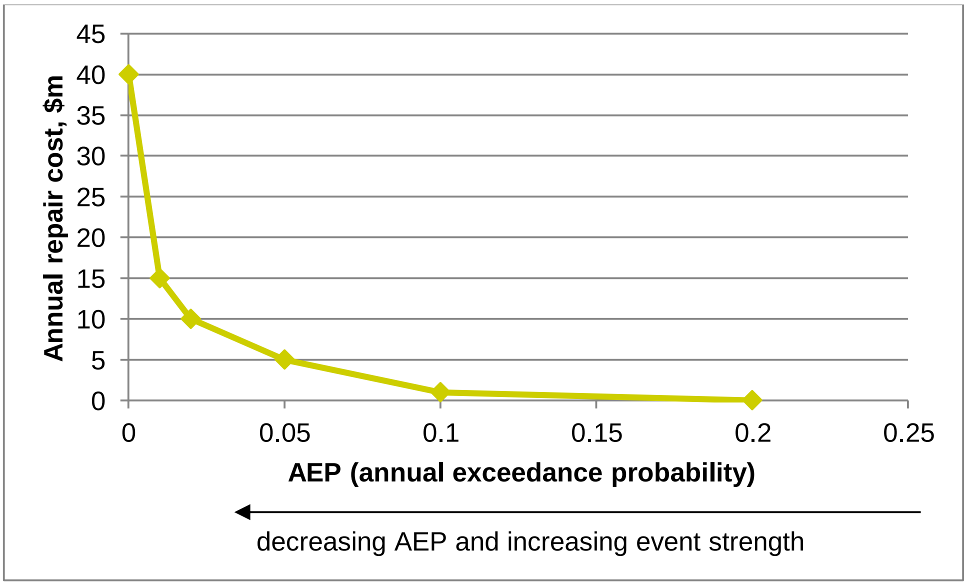
The repair cost for the events with AEP lower than 0.2 ranges from $1 million for an AEP 0.1 event to $40 million for an AEP 0.0001 event. Plotting repair cost across the various events, each represented by an AEP value, produces the annual repair cost curve shown in Figure 2.

Table 3 Repair costs by ARI and AEP

ARI (approximate)	AEP	Road Repair Cost
5	0.2	$0
10	0.1	$1 000 000
20	0.05	$5 000 000
50	0.02	$10 000 000
100	0.01	$15 000 000
10 000	0.0001	$40 000 000

Source: See Table 4

Figure 2 Annual repair cost by AEP



The expected, or average, annual repair cost can then be calculated as the area under the Figure 2 repair cost curve (– by estimating the areas of the triangles and rectangles under the cost curve). Table 4 shows the calculated component areas of rectangles and triangles between consecutive AEP values.

For example, for events between AEP 0.0001 and AEP 0.1 in Figure 2, the areas are calculated as follows:

- Triangle: ($40 000 000-$15 000 000)*(0.01-0.0001)*0.5 = $123 750
- Rectangle: $15 000 000*(0.01-0.0001) = $148 500
- Total: = $272 250

Table 4 Estimation of average annual repair costs

AEP	Repair cost	Area triangle	Area rectangle	Total	Cumulative area
0.01 to 0.0001	$40 000 000	$123 750	$148 500	$272 250	$272 250
0.02 to 0.01	$15 000 000	$25 000	$100 000	$125 000	$397,250
0.05 to 0.02	$10 000 000	$75 000	$150 000	$225 000	$622,250
0.10 to 0.05	$5 000 000	$100 000	$50 000	$150 000	$772,250
0.20.to 0.10	$1 000 000	$50 000		$50 000	$822,250
Total		$373 750	$448 500	$822 250	

The level of flood immunity can be improved by raising the height of the road. As flood immunity improves (shown as movements leftwards along the cost curve), the average annual repair cost (area under the cost curve) reduces. This is seen in the right hand column of Table 4 which reports the cumulative area under the cost curve to progressively higher AEP values. For example, if immunity was to improve from AEP 0.2 to AEP 0.05, average annual repair costs would reduce from $822 250 to $622 250, a reduction of $200 000.

4. Non-monetised or difficult to monetise benefits

Flood resilience improvements can give rise to a range of benefits that cannot be estimated by reference to user costs. Specialist expertise and/or data collection is needed to estimate these categories of benefits, which means estimation might not be worthwhile other than for high impact flood events. This category of benefits includes:

- **Loss of perishable goods:** Some products particularly fruit and vegetables can be damaged in transit due to flood delays, or lose condition on-farm or in processing sheds waiting for transport. Damage can only be established by surveys of growers or processors which might only be warranted for very large flood events which have extensive network impacts. For produce that has to be destroyed because of delay related damage, the loss is equal to the full wholesale price net of GST. For goods that lose some of their quality, the loss is the difference between the normal wholesale price at that time of year and the price actually achieved times the volume sold at wholesale.
- **Emergency services costs:** These are inherently difficult to estimate for two reasons:
  - Maintaining emergency services response capability is a normal function of government, the costs of which might not be affected by a change in flood risk at any one site
  - Emergency services response is likely to vary significantly according to event impact – the isolated flooding of one stream might not induce an emergency services response but cyclone-related flooding or flooding from a severe thunderstorm could draw a large emergency service response, not all of which would be applied to facility related flooding.

  If estimation of savings in emergency services is being contemplated, the analytical effort would only be worthwhile for large, higher impact events[4].
- **Excess inventories:** Some retailers and service providers (for example, tyre and mechanical repairers, hardware stores) may stock additional inventories of product and parts in anticipation of a major flood event. The value of any excess inventories can only be established by survey which should be preceded by exploratory consideration as to the value of the research required.

  The cost of the additional inventories is equal to the holding cost rather than the value of the inventories themselves. If for example a retailer purchases $100 000 of stock one month earlier than normal and the retailer's normal cost of finance is 13% pa, the additional inventory cost would be $1 083[5] .

  Even if inventory data could be obtained, there will sometimes be difficulties in attributing savings in inventory costs to any one particular flood resilience initiative. In some parts of Australia excess inventories may be carried in response to network flooding risk which occurs at multiple sites. Where this is the case, inventory costs will be reduced only where network flooding risk is reduced.

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[4] Emergency services costs as a proportion of the total tangible cost of flood events were estimated by BTRE (2001) for the 1990 Nyngan NSW flood as being 10% of total tangible damage costs. For the 2011 Queensland floods Deloitte Access Economics (2016) estimated emergency services costs to be 2% of total tangible damage costs.

[5] The monthly interest cost equals $100 000*0.13/12

- **Loss of access to essential services:** Some flood events may cause people to be cut off from hospital, medical and educational services and from everyday goods and services. This degree of disruption is likely to be associated with large, region-wide events which cause network-level disruption. Individual flood resilience initiatives on their own might not reduce these costs of isolation. For these large events, some costs might be capable of estimation with sufficient analytical resources – such as medical evacuations – but the challenge still remains that individual isolated initiatives might not influence these costs.
- **Environmental impacts:** There may be savings in environmental damage from less materials of flooded facilities being washed away into surrounding areas and waterways.

5. Areas for future research

Little is known about how users respond to imminent and actual flooding. Useful topics for research could include:

- How users interpret flood warning information
- Whether, and if so how, users manage their activities in anticipation of and during facility closures
- Whether users ‘weight’ the costs of waiting at a closed facility relative to the costs of dry weather travel time or time spent diverting around a closed facility
- Whether user response to closure is affected by the scope (the number of facilities closed) and scale (the duration of closure) of flood events in transport networks they intend using.

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