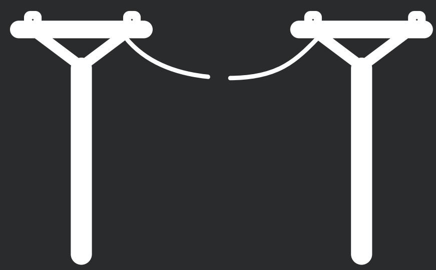
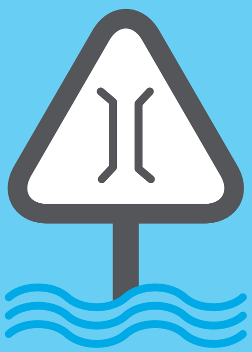
Costs flowing from disruptions to infrastructure during natural disaster events



A single loss of electricity supply incident caused by bushfires in 2007 in Victoria cost about

$234m



Lifetime costs of repeated closures to the Emile Seriser bridge in Dubbo, NSW, due to floods are about

$92m

Each day of lost mobile services during the 2011 Brisbane floods cost about

$1m

3. The economic case for change – infrastructure projects

Key points

- When natural disasters affect critical infrastructure, they impose significant costs on communities and impede their ability to react and recover. Early consideration of resilience in infrastructure decision-making would likely change the scope, design and construction of essential assets
- This chapter uses three case studies to consider the economic case for resilient infrastructure. It calculates an ex-post net benefit framework for assets affected by past disasters. The case studies are:
  - Electricity transmission lines in Victoria
  - The Emile Serisier Bridge in New South Wales (NSW)
  - Communications infrastructure in Queensland
- These case studies do not provide a full cost-benefit analysis (CBA) of resilience measures, but they do highlight the potential benefits of incorporating resilience measures early in the investment planning process.

Very often the role of infrastructure in supporting community resilience only becomes clear after a natural disaster. The three case studies presented here demonstrate this by comparing the potential benefits of resilience measures undertaken after an event relative to the costs of these measures. They show that, implementing resilience measures would have net benefits given the natural disaster that eventuated.

However, it is complex to determine which resilience measures are appropriate before a natural disaster and indeed before infrastructure is built. It requires a detailed ex-ante assessment of the likelihood of a hazard affecting a proposed asset and analysis of the possible resilience options that could be implemented to mitigate impacts. Nevertheless, these case studies are useful illustrations of the merit of including resilience in infrastructure decision-making.

The case studies demonstrate variations in:

- The type of infrastructure affected
- The type of natural disasters
- The impact on communities when infrastructure is damaged or destroyed
- The geographic areas and communities affected
- The actions taken to boost resilience after these disasters.

To assess the potential net benefits of implementing resilience measures, the case studies compare the direct costs (for example, the cost of building a new bridge or underground electricity lines) with relative benefits (for example, the avoided disaster costs attributable to resilience measures). They examine:

- The impact of bushfires on **electricity transmission lines in Victoria**
- The effect of flooding on the **Emile Serisier Bridge in NSW**
- The effect of flooding on **communications infrastructure in Queensland.**

3.1 Electricity lines in Victoria

Australia has one of the world's largest interconnected electrical grids (Australian Energy Market Operator, 2015). The National Electricity Market (NEM) connects NSW, Queensland, South Australia, Tasmania and Victoria into a single grid that covers about 19 million residents.

Victoria and NSW are primarily linked by two 330-kilovolt overhead transmissions lines that pass through north-east Victoria. The lines share a 340-kilometre easement from South Morang in Victoria to the Murray Power Station in NSW, via the Dederang terminal (Figure 3.1).

Bushfires can cause electricity service outages. While overland transmission lines have caused some of the bushfires in Victoria, this case study focuses on how electricity infrastructure can be made more resilient to reduce the impact of bushfires on essential electricity services.[5]

This case study examines the Tatong bushfire in January 2007, which resulted in the loss of both transmission lines connecting Victoria to NSW. The case study assesses the potential net benefits of implementing proposed measures to boost resilience if a similar disaster occurs. The case study suggests that changing the design and construction of these lines to improve resilience in at-risk areas may be economically feasible.

Figure 3.1: Electricity transmission lines connecting Victoria to NSW

Source: Google Earth (2015); Orr & Allan (2015)

5. In November 2015, the Victorian Government announced new regulations that require electricity distribution companies to introduce technology that reduces the chance of powerline faults causing bushfires. The proposed *Electricity Safety (Bushfire Mitigation) Regulation 2015* will also require companies to progressively replace powerlines in high-risk areas by insulating the cables or burying them underground (Victorian Government, 2015). While these proposed changes focus on reducing the risk of bushfires caused by powerlines, this case study examines the case for making powerlines more resilient from the effects of bushfires established through other causes.

3.1.1 The Tatong bushfire – 16 January 2007

The Tatong bushfire developed from a lightning strike on 11 January 2007. By 16 January 2007, spot fires had merged, covering a significant part of rural Victoria.

Authorities notified the operators of the transmission lines and the NEM, SP AusNet and the National Electricity Market Management Company (NEMMCO)[6], that the fire could cross the easement north of Toombullup, placing the lines at risk.

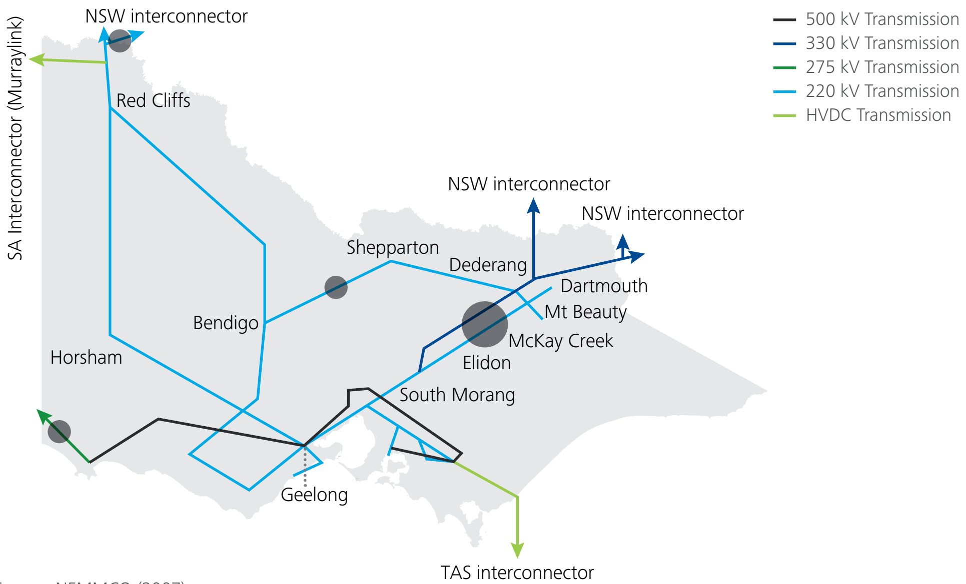
While the operators knew that both lines were at risk, SP AusNet considered this 'worst-case scenario' unlikely (Nous Group, 2007). Rather, it expected that if the fire did affect one of the lines, it would automatically reclose (that is, close the circuit to restore power) and almost immediately return to service.

The fires entered the easement at about 3.50 pm. SP AusNet notified NEMMCO, stating that it expected to lose the lines one at a time. At 4.00 pm the fire caused one line to flashover (electrically discharge). The line automatically reclosed, which allowed supply through these lines to resume, but, soon after a second flashover occurred, causing this line to be locked out of service by the control system.

The second line then experienced a flashover, cutting off NSW and Queensland from South Australia, Victoria and Tasmania. This resulted in increased electricity flow from South Australia into Victoria, as South Australia tried to meet the supply shortfall from the loss of electricity from NSW. This large quantity of electricity exported from South Australia to Victoria tripped the South Australia to Victoria line. Thus, as shown in Figure 3.2, the national grid was separated into three 'islands': Queensland, NSW and parts of northern Victoria; most of Victoria and Tasmania; and South Australia.

At 4.03 pm, an automated load-shedding process (initiated to stabilise the system) cut power to about 481,345 Victorian electricity customers. It took 4.5 hours to restore full supply, during which time energy was exported from Victoria to South Australia. Later, a further 205,887 customers lost supply due to manual load shedding. It took another four hours after supply was restored for the electricity network configuration to return to normal. Overall, about 7,100,000 kilowatt hours of electricity was lost to 620,342 households and 66,890 businesses, as well as disruptions to major public infrastructure and public hospitals (Nous Group, 2007).

Figure 3.2: Points of electrical separation during the Tatong bushfire – Victorian region



Source: NEMMCO (2007)

6. SP AusNet is now known as AusNet Services, and NEMMCO has been succeeded by the Australian Energy Market Operator.

3.1.2 Emergency response focus of post-event reviews

Given its significant impacts, the disruption to Victoria's transmission network has been reviewed by:

- The Australian Energy Regulator (AER)
- NEMMCO
- Nous Group, on behalf of the Department of Primary Services.

These reviews focused primarily on emergency response issues, particularly in relation to NEMMCO's decision not to re-classify the concurrent loss of both lines from a non-credible to a credible contingency. NEMMCO had the power to do so under abnormal conditions, including bushfires, but no obligation. Reclassification is fairly common, especially during lightning storms. In fact, the loss of both lines had been declared credible twice in the previous year. If reclassified, the power system would be adjusted to better withstand the new contingency. This would have led to a reduction in reliance on imports, mitigating – and possibly eliminating – the need for load shedding.

The guidelines for action under abnormal conditions have significantly expanded since the event. The Australian Energy Market Operator (AEMO) must now notify market participants if it believes a non-credible contingency is likely as a result of abnormal conditions, even if it has not reclassified the contingency as credible.

Vegetation clearance regulations have also been changed in Victoria. In 2010, a clause that exempted small tree branches from minimum clearance spaces for aerial bundled and insulated cables was removed. More recently, the *Electricity Safety (Electric Line Clearance) Regulations 2015* has reintroduced some flexibility, providing:

- Electricity operators the ability to propose alternative methods to ensure safety and resilience other than the stated minimum clearances. For example, operators could suggest compliance using cable technology not specifically stated in the regulation
- A more flexible definition of 'insulated cable', reducing the minimum clearance for some lines.

Better technology may also help the inspection of clearances. For example, operators could use unmanned aerial vehicles (commonly called drones) to monitor the easement and ensure compliance.

Technological improvements have also lessened the risk of high-voltage lines igniting bushfires. A key technology is the Rapid Earth Fault Current Limiter, developed in Victoria in response to the 2009 Victorian Bushfires Royal Commission. These are installed at substations to stop the electrical current within milliseconds of a power line coming into contact with the ground or vegetation. The system may be triggered when a tree falls on a power line or a cable hits the ground. The limiter then reduces the voltage to a low current flow insufficient to spark a fire. Forty-five limiters will be installed across Victoria over the next seven years.

While these changes are commendable, the reviews have made little assessment of whether it is cost-effective to make Victoria's transmission line infrastructure more resilient to lessen reliance on operational responses to manage electricity supply. This is despite authorities knowing that the transmission lines are still exposed to bushfire risk, with experts confirming that vegetation clearance standards are insufficient to protect overhead electricity lines from loss of service during a bushfire. For example, Nous Group notes that:

'Line design experts advised Nous that the task of designing a tower line that will consistently remain in service with a bushfire in the easement is 'impossible'. Nous concluded that improved vegetation clearances would not have prevented the loss of the lines to the fire on 16 January 2007.' (2007:86)

3.1.3 Applying a CBA framework for infrastructure resilience

Many factors need to be considered in determining if it is economically feasible for infrastructure to be made more resilient. This case study will examine the cost of each resilience option and how this compares to its benefits (for example, avoiding the cost of an outage). The risk factor is used to balance the cost and benefits, indicating the level of risk to ensure this investment will break even if a similar event occurs.

This analysis is based on ex-post event data and is used to demonstrate the hypothetical level of risk that would ensure the benefits equal the costs for a specific resilience measure.

The results suggest the benefits of replacing sections of the South Morang to Murray Power Station transmission line with underground cables in at-risk areas would exceed the costs, if the risk of a bushfire similar to the Tatong bushfire were greater than 5% a year.

This section outlines the CBA framework in the following stages:

- Identifying resilience options
- Identifying and valuing benefits and costs
- Calculating the risk threshold.

3.1.3.1 Identifying resilience options

There will always be some risk that overhead power lines are lost to service when a bushfire enters an easement. Nous Group (2007) identified a number of options to improve the resilience of power lines. These include:

- Changing vegetation clearance standards around overhead power lines
- Separating the two 330-kilovolt transmission lines into their own easements
- Replacing overhead lines with underground transmission cables.

A summary of the advantages and disadvantages of these options is presented in Appendix C. While these were reviewed by Nous Group (2007), their report focused on the relative costs of different options and did not specifically consider potential resilience benefits.

One resilience measure identified was replacing overhead lines with underground transmission cables. This option is commonly rejected because the cost of laying underground cables is significantly more than overhead power lines. For instance, Nous Group concluded that:

'Underground cable is prohibitively expensive for long-haul, high-capacity links.' (2007:87)

In many studies, it is not evident whether a CBA was undertaken to assess if the reduction in disaster risk would outweigh these additional costs.

Given that replacing overhead lines with underground cables is likely to reduce risk the most, this option has been selected for the case study. A CBA framework has been used to analyse the feasibility of this option (that is, if embedding resilience in this way will deliver net benefits for society). The analysis compares the probability of a similar bushfire occurring to the risk factor required to equate the expected benefits with the cost of the resilience measure.

Identifying and valuing costs and benefits

Authorities are aware that the electricity transmission lines connecting Victoria to NSW are exposed bushfire risk. However, estimating the risk of both lines being lost in a bushfire requires sophisticated risk modelling and scenario analysis. The likely variation in the severity of disruptions associated with bushfires would need to be assessed, recognising that future disruptions could be less or more severe than those caused by the Tatong bushfire of 2007.

Recognising this uncertainty, this case study estimates a risk threshold, above which the benefits of installing underground transmission cables are likely to exceed the costs. This demonstrates how a CBA framework for resilience can be applied.

Key considerations of both the benefits and the costs of underground transmission cables are outlined in Figure 3.3. Given the level of risk is uncertain, these figures are approximate and have been rounded for presentation purposes. The figures are designed to provide guidance on the magnitude of costs and are not exact.

Valuing the costs

A valuation of resilience costs should encompass whole-of-life costs relative to the business-as-usual alternative. Thus, it is important to consider the up-front costs of installing underground transmission cables and if the operating and maintenance costs of cables are higher or lower than the costs of the current overhead lines.

Installing underground cables is expensive because trenches or tunnels must be dug. Other cost factors are route length, route terrain, cable voltage, whether direct or alternating current (DC or AC) technology is used, and transmission capacity. Installing underground cables is estimated to cost between five and 10 times more than installing overhead power lines (Power and Water Corporation, 2009; Hill Michael, 2009; Western Power, 2011).

Estimates from Australian and international sources suggest installing underground transmission cables could cost between $2 million and $24 million per kilometre (see Appendix C). For this analysis, the average cost estimate of $11 million per kilometre has been used.

A sensitivity analysis will also be performed for the following figures:

- $7.0 million – the cost to place a 330-kilovolt transmission line underground (similar to the transmission lines in this case study) according to Diona Civil Engineers
- $11.2 million – the cost to place a 200-kilometre, 400-kilovolt transmission line underground according to PB Power in New Zealand
- $23.9 million – the cost to place a 75-kilometre, 400-kilovolt transmission line with 6,930 megavolt-amperes (MVA) underground according to Parsons Brinckerhoff in the UK, is also the upper limit of the costs in our literature review.

The net increase in operating and maintenance costs for underground cables relative to overhead power lines is more difficult to quantify. While underground cables are likely to experience fewer outages than overhead lines, identifying and repairing faults in underground cables is more costly and takes longer (ICF Consulting, 2003).

A study undertaken between 1998 and 2002 in North Carolina in the US found that underground outages took 58% longer to repair but occurred half as often (Matanuska Electric Association, 2015). On this basis, it is assumed there would be a minimal net increase in operating and maintenance costs if overhead cables were replaced with underground cables.

Figure 3.3: CBA framework for underground electricity transmission cables

Costs		Benefits	
Quantitative	**Qualitative**	**Quantitative**	**Qualitative**
• Installation costs	• Net increases in operational and maintenance costs relative to overhead lines, taking into account that: – Underground cables can be more reliable than overhead lines as they are protected from winds and storms – Repairs to underground cables can take weeks or months, compared to days or hours for overhead lines.	• Increased power line reliability during bushfires, including: – Sustained supply of electricity to households and businesses – Sustained supply to other public infrastructure (e.g. transport and health services) • No more need to prune vegetation where underground cables are installed.	• May be limited due to the low population in these areas. Benefits may include: – Improved visual amenity – Reduced personal safety hazards from falling power lines and car accidents involving power poles.

Source: Deloitte Access Economics (2016)

Valuing the benefits

While the costs associated with underground cables are high, they must be evaluated in the context of the potential benefits. The main benefits are:

- a more reliable electricity supply (as captured by the avoided costs of disruption)
- the avoided costs of an emergency response.

The value that electricity customers place on a reliable electricity supply can be quantified using value of customer reliability (VCR), measured by the AEMO (2014). Updating the average value reported for Victoria to 2015–16 prices using the consumer price index (CPI) produces a value of $32.98 per kilowatt hour. The impacts included in this cost are explained in Box 7.

As noted, Nous Group (2007) estimated the Tatong bushfire caused 7,100,000 kilowatt hours of lost supply for Victorian households and businesses. This indicates that preventing similar electricity disruptions to households and businesses is worth about $234 million per event.

It is also important to value the reliability of electricity supply for public infrastructure, since it is not captured in the VCR estimates. Nous Group (2007) estimates these costs are about 25% of the household and business costs previously outlined, representing an additional cost of $59 million per major disruption event. This is an added avoided cost or benefit of placing transmission lines underground.

In the case of the Tatong bushfire, impacts to public infrastructure included:

- Lost traffic lights at 1,100 intersections throughout Victoria, leading to major traffic delays and police traffic controllers at high-priority locations
- Delays to and overcrowded tram services due to traffic disruptions
- Disruptions to trains, including 160 cancelled services and 616 delayed services. The total delay was estimated at about 2.5 million person-minutes
- The shutdown of 141 mobile telecommunications network base stations
- Four hospitals experiencing difficulties shifting to backup generators. Three hospitals were able to continue services without significant problems, however some patients at Geelong Hospital were transferred to other locations
- The cost of hiring a replacement generator to preserve consumables at the Red Cross Blood Service
- The cost of preparing to move tissue supplies at the Donor Tissue Bank to alternative storage
- Lift failures, loss of water supply and loss of air-conditioning in some high rise buildings
- The cost of arranging emergency services staff members to respond to a high number of 000 calls – 33% above average.

Box 7: Value of consumer reliability (VCR)

The VCR estimates consumers' willingness to pay for reliable electricity supply in dollars per kilowatt hour. This includes residential, commercial, agricultural and industrial users, and customers directly connected to the transmission network.

To calculate the values, the AEMO conducted surveys asking consumers how much they would pay to avoid various outage situations. Based on a standard weighting of electricity user types in Victoria, the VCR is estimated at $32.98 per kilowatt hour, in 2015–16 price terms.

The impacts valued in this VCR estimate include:

- Loss of work from paid staff
- Lost production
- Extra time taken to complete tasks
- Loss of revenue from fewer sales
- Spoilage of perishable products
- Loss of livestock
- Business downtime
- Loss of heating or air-conditioning.

Source: AEMO (2014)

The total disruption costs of about $293 million (avoided costs and benefits of the resilience measure) are translated to an average expected annual cost using the risk threshold calculated in the following section. In addition, placing transmission cables underground would reduce the costs of managing vegetation, which is only required for overhead lines. For the purpose of this analysis, a saving of about $769 per kilometre of underground cables installed is assumed.

Improvements to visual amenity and personal safety have been considered qualitatively. Noting that the transmission lines are in lightly populated areas, it is likely these benefits are negligible in this analysis.

Box 8: Quantifiable costs and potential benefits of the Tatong bushfire

The potential benefits of laying the electricity cables underground are:

- Avoided costs/benefits of about $293 million per event. About $234 million is the cost of lost supply to customers and businesses, and $59 million is the cost of lost supply to public infrastructure
- Avoided vegetation management costs of around $769 per kilometre.

The cost of laying underground transmission cables is about $11 million per kilometre.

Using these numbers, a threshold level of risk can be calculated.

Calculating the risk threshold

A comparison of the quantified costs and benefits described in this report can be used to derive the threshold level of risk. This threshold describes the level of risk that needs to be exceeded for the benefits of installing underground cables to exceed the costs.

Specifically, assume that a decision was made to replace the existing transmission line route between South Morang and the Murray Power Station with underground cables. The benefits would exceed the costs if the likelihood of a bushfire occurring, similar to the Tatong bushfire, exceeded 47% per year. These calculations are presented in Table 3.1.

Given the risk of major disruption events like the Tatong bushfire is likely to be less than 47% per year, it is clear that installing underground cables for the length of the easement would not pass a CBA.

However, a more targeted approach of installing underground cables in the parts of the easement at greatest bushfire risk may be economically feasible. Analysis by Insurance Australia Group (IAG) indicates that about 11% of the easement from South Morang to the Murray Power Station passes through forested areas with higher bushfire risk.

Assuming that focusing on these higher-risk areas would build enough resilience against events like the Tatong bushfire, it is estimated the benefits would exceed the costs if the likelihood of a similar event exceeded 5% per year. These calculations are presented in Table 3.3 (page 52).

A sensitivity analysis of this scenario is presented in Table 3.4 (page 52). The analysis shows that, using this approach, this measure is more likely to pass a CBA since a lower threshold is required to ensure that the investment breaks even.

3.1.4 Lessons learnt

This case study suggests it can be economically feasible to build resilience into electricity transmission infrastructure where CBAs take risks into account. However, site-specific costing and scenario analysis is needed to confirm these results.

The study highlights some of the challenges of identifying options for resilience before a disaster event. It also emphasises the need for detailed risk assessment. While placing transmission lines underground for the entire easement is not economically feasible, there could be net benefits from targeting high-risk sections.

Further, the study shows that the broader community receives most of the benefits from more resilient infrastructure. As such, without appropriate incentives, infrastructure owners and operators are unlikely to invest in resilience beyond the minimum regulatory requirements. Adoption of the practical guidance in chapter five of this report will help to improve these incentives and ensure resilience options are evaluated as part of the economic appraisal process.

Table 3.1: Comparison of costs and benefits in complete replacement scenario – ~47% risk threshold

CBA component	Costs (NPV, $m)	Benefits (NPV, $m)
Installation of 340 km of underground cables (Up-front cost of $3.7 billion, calculated as $10.8 million per km x 340 km)	3,562	–
Increased reliability of supply to households and businesses (Average annual benefit of $110 million, calculated as $234m per event x 47.2% annual risk of event)	–	2,844
Increased reliability of supply for public infrastructure (Average annual benefit of $28 million, calculated as $59m per event x 47.2% annual risk of event)	–	711
Reduced vegetation management costs (Annual benefit of $0.26 million, calculated as $796 per km x 340 km)	–	7
Total	**3,562**	**3,562**

Source: Deloitte Access Economics (2016)

Table 3.2: Sensitivity analysis for a 340-kilometre installation

Cost ($m)	Risk threshold
$7.0	30.5%
$10.7	47.2%
$11.2	49.0%
$23.9	104.8%

Source: Deloitte Access Economics (2016)

Table 3.3: Comparison of costs and benefits in at-risk replacement scenario – ~5.1% risk threshold

CBA component	Costs (NPV, $m)	Benefits (NPV, $m)
Installation of 37 km of underground cables (Up-front cost of $399 million, calculated as $10.8 million per km x 37 km)	387	–
Increased reliability of supply to households and businesses (Average annual benefit of $12m, calculated as $234 million per event x 5.13% annual risk of event)	–	309
Increased reliability of supply for public infrastructure (Average annual benefit of $3 million, calculated as $59 million per event x 5.13% annual risk of event)	–	77
Reduced vegetation management costs (Annual benefit of $0.03 million, calculated as $796 per km x 37 km)	–	1
Total	**387**	**387**

Source: Deloitte Access Economics (2016)

Table 3.4: Sensitivity analysis for a 37-kilometre installation

Cost ($m)	Risk threshold
$7.0	3.3%
$10.7	5.1%
$11.2	5.3%
$23.9	11.4%

Source: Deloitte Access Economics (2016)

3.2 Emile Serisier Bridge in New South Wales

The city of Dubbo sits at the intersection of two important motor freight corridors: the Newell Highway, which runs north–south, linking Queensland to Victoria; and the Mitchell Highway, which runs east–west, linking inland Australia to the NSW coast. Thus, Dubbo is a major motor freight hub.

To pass through Dubbo, visitors must cross the Macquarie River. There are two primary motor vehicle bridges over the river: LH Ford Bridge,[7] a high-level two-lane bridge; and Emile Serisier Bridge, a low-level four-lane bridge. About 20,000 vehicles use LH Ford Bridge each day, and about 15,000 use Emile Serisier Bridge (JL Kilby, 2013).

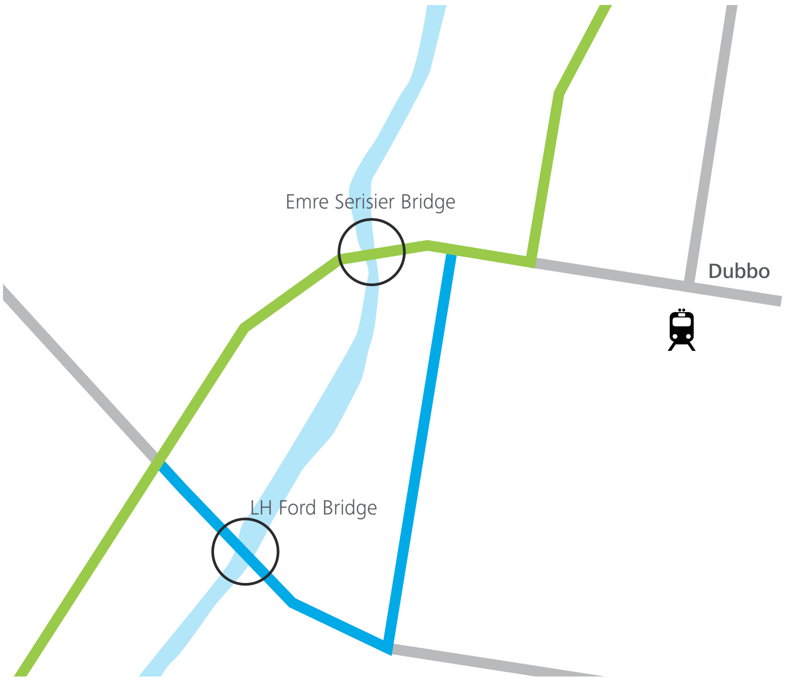
This case study highlights the importance of detailed risk assessments and evaluating options.

3.2.2 The impacts of repeated flooding

The Macquarie River is prone to flooding that usually lasts two to three days but can persist for up to two weeks. Because of its low level, the Emile Serisier Bridge has been flooded six times since it was built in 1987: three times in 1990 and once in 1998, 2000 and 2010. Once the river reaches flows of between 58,000 and 61,000 megalitres per day, the bridge is inundated and unusable (Pitt and Sherry, 2013).

The bridge deck stands at 257.6 metres on the Australian Height Datum (AHD), which roughly gives the average sea level in Australia, while the one-in-10-year flood level is 259.97 metres AHD. Thus, during a one-in-10-year flood, the bridge is more than two metres underwater. The interruption lasts until water falls below the deck level and debris can be removed.

Figure 3.4: Location of Emile Serisier Bridge in Dubbo and alternative route



Source: Google Maps (2015)

7. The low-level Troy Bridge also crosses the Macquarie River. However, it is an extremely small bridge not suited to through traffic and would be unusable in any situation in which the Emile Serisier Bridge is inundated.

When the Emile Serisier Bridge is inundated, traffic must be diverted to the LH Ford Bridge, which can withstand a one-in-50-year flood. This creates a significant bottleneck since the LH Ford Bridge only has two lanes and already operates at more than 90% of its capacity during normal peak hours (Pitt and Sherry, 2013). During the flood in 2010, it took more than two hours to cross the river – a trip that typically takes 10 minutes. Such congestion imposes significant costs to Dubbo residents, visitors and through traffic.

A 2013 report by Pitt and Sherry, prepared for Dubbo City Council, documents the economic costs (including the cost of social impacts) that the 2010 floods and subsequent Emile Serisier Bridge closure imposed.

For example, services at the Dubbo Base Hospital, which caters for the greater regional area, were disrupted, especially for outpatients. Numerous school and university classes were disrupted, with many students staying home for the duration of the flood. Dubbo Buslines estimates that roughly 50% of its usual students stayed at home. Visitor numbers at the main shopping centre increased, as the central business district was inaccessible, but revenue at other shops declined. Residents stuck in traffic lost leisure and working time, and fire, police and ambulance services' response times worsened.

Tourism services were also affected. Dubbo's leading tourist attraction, the Taronga Western Plains Zoo, lost about $170,000 of revenue due to floods. Local visitors were also affected, in part due to the difficulty of crossing the river – 'An evening function during the flood was attended by 25 rather than the expected 150 people' (Pitt and Sherry 2013).

Traffic increased the wage and fuel costs of the many freight businesses that pass through Dubbo. Time was lost and deliveries were delayed. Greenhouse gas emissions and other negative environmental externalities such as pollution would have worsened due to the heavy congestion.

Table 3.5: Flood impacts on infrastructure

Year	Floods and bridge closure duration	Total days lost
1990	5 days in April, 3 days in July, 14 days in August	22
1998	2 days in August	2
2000	4 days in November	4
2010	13 days in December	13
		41

Source: Pitt and Sherry (2013)

Table 3.6: Inundation levels of Dubbo bridges

	Emile Serisier Bridge	LH Ford Bridge
Deck level (m AHD)	257.63	262.09
1-in-10-year flood (m AHD)	**259.97**	260.06
1-in-20-year flood (m AHD)	**260.43**	260.49
1-in-50-year flood (m AHD)	**261.54**	261.74
1-in-100-year flood (m AHD)	**262.84**	**263.08**
1-in-200-year flood (m AHD)	**263.72**	**263.94**

Bold = bridge flooded

Source: Cardno Wiling (2010)

3.2.3 Other analysis

A Pitt and Sherry report (2013) recommended duplicating the LH Ford Bridge at an estimated cost of $30 million. The duplication was compared to building a low-level bridge near Tamworth Street at a considerably cheaper cost of $10 million, conceivably funded by the council. This option was rejected because it failed to provide resilience to floods. The report estimated that duplicating the LH Ford Bridge had a benefit-cost ratio (BCR) of 6.6. The main potential benefit would be increased resilience to flooding, with reduction in day-to-day congestion a secondary benefit.

The benefits are likely to accrue to through traffic more than local residents. As such, it would be appropriate for the NSW or Australian government to contribute towards project funding. Since the report was published, the NSW Government has announced its intention to duplicate the LH Ford Bridge at a cost of $50 million (Baird, 2015).

Box 9: The importance of a holistic perspective

The Emile Serisier Bridge is a single section of the Newell Highway. Any study of the resilience of the bridge must consider the roads that feed it. Little would be gained by flood proofing the Emile Serisier Bridge if it simply moved the congestion from the area surrounding the crossing to another non-resilient section of the highway. It is therefore worth noting that sections of the Newell Highway north of the bridge are also susceptible to flooding (Cardno Wiling, 2010). Any plans to improve the resilience of the bridge would need to include Newell Highway upgrades.

3.2.4 Modelling the cost of resilience

Deloitte Access Economics has estimated the cost of Emile Serisier Bridge closures due to flooding over the past 28 years and the estimated future costs if no changes or duplications were made to the bridges. The historical cost of the Emile Serisier Bridge's closure due to flooding is estimated at around $17 million. The expected future cost, if no changes are made, is approximately $75 million.

This means that if the bridge had originally been built with appropriate resilience measures, the avoided costs would be approximately $92 million. In other words, the government could spend up to $92 million (in present value terms) to build a more resilient bridge and accompanying highway section and still yield a net benefit.

To provide some context, the estimated replacement cost is $7.4 million and the current written down value is $5.4 million. This suggests that the cost of the disruptions to date more than doubles the replacement value of the bridge. The cost of future disruptions is about 10 times more than the cost of replacement. Taking this into account, it is unlikely that flood proofing the bridge would cost $92 million in present value terms if the estimated replacement cost is $7.4 million.

In the analysis, the following assumptions were made:

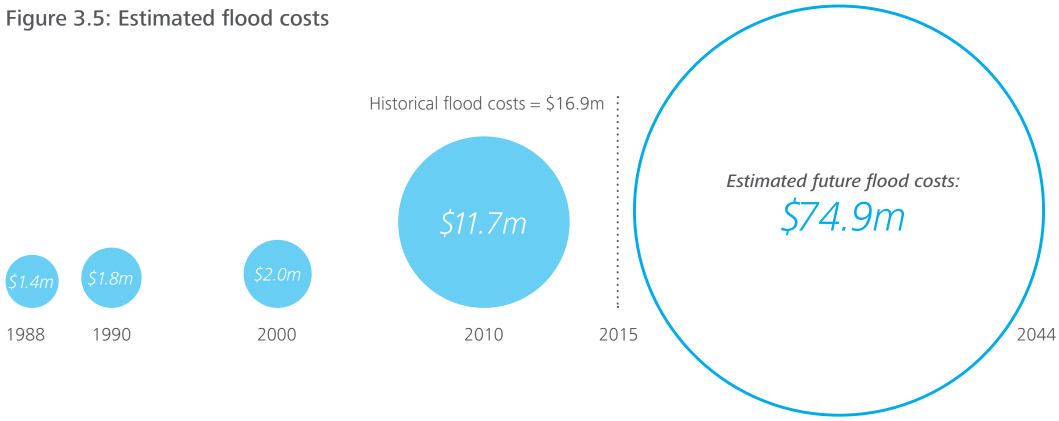
- A discount rate of 3% was used for costs[8], while traffic was assumed to grow at 3.5% per annum (the recent historical average [JL Kilby, 2013])
- The value of travel time savings (VTTS) was calculated by employing the standard used by Roads and Maritime Services
- Historical data was used for past flood events, and future flood events were assumed to continue at the historical rate.[9]

If the present and expected future benefits are considered, the expected cost of duplicating the LH Ford Bridge is $48 million in net present value terms. Against an avoided cost of $75 million, this suggests an ex-post BCR of at least 1.6. Using the cost estimate provided by the Pitt and Sherry report (2013) of around $30 million, this would suggest a BCR of 2.5.

8. Throughout the case studies, a 3% discount rate is used, as it was in the first Roundtable report. It represents the social discount rate of the expected benefits for infrastructure and other public projects. In Arrow et al. (2012), a discount rate schedule has been provided for different time horizons. For periods within the near future (that is, within years six to 25), a 3% marginal discount rate is appropriate.

9. This represents a conservative future rate: the past 28 years coincided with significant periods of drought, which likely reduced the frequency of flooding. The CSIRO expects that climate change, while decreasing average rainfall, will increase the future rate of floods due to increased climate volatility.

Figure 3.5: Estimated flood costs



Source: Deloitte Access Economics (2016)

3.2.4.1 Limitations

This case study measured resilience benefits in terms of less traffic congestion during floods. Yet, duplicating the LH Ford Bridge has benefits outside of flood times too, including smoother traffic. There are also social benefits associated with resilience (discussed in Section 3.2.2) that are potentially significant, but not quantified due to the lack of data. Essentially though, they include social impacts that could have been avoided if the bridge did not flood, including:

- Disruption to fire, police and ambulance services' response times
- Disruption to schools and universities
- Lost business due to lack of access
- Disruptions to leisure and working time.

Guidance on evaluating these social impacts can be found in the Roundtable report, *The Economic Cost of the Social Impact of Natural Disasters* (2016). If these benefits were included, the total net benefits from investing in resilience would be even greater than those presented here.

Further, this case study assumes that current risks will continue to apply in the future. Consequently, the BCR is likely to vary with a change to the risk of flooding and/or the predicted traffic flow. Detailed hazard assessment modelling is required to evaluate options for resilience.

3.2.5 Lessons learnt

The failure to properly consider flood resilience when planning the Emile Serisier Bridge has lead to significant avoidable costs. Even minor or short-term disaster impacts in a local area can be significant when considered over the life of the asset. This case study highlights the need to consider options for greater resilience in making investment decisions.

It is possible that flood risks were considered to some extent while the bridge was being planned, but appropriate evaluation was limited by a lack of flood data. Dubbo City Council had records of daily river flow levels from 2 May 1956 (Pitt and Sherry, 2013). Further, in 1978 (prior to the bridge's construction in 1987), the Water Resources Commission (Cardno Willing, 2010) wrote a report on flood frequencies. Interestingly, the 1978 report contained significantly lower estimates of flood heights than later reports (Water Resources Commission 1979, cf. Cardno Willing, 2010). This may have led the council to underestimate the number of times the Emile Serisier Bridge would be inundated if built at a low level. In hindsight, it is evident that a greater investment in resilience would have been warranted.

This case study accentuates the importance of data and technical modelling capabilities to assess disaster risks and inform investment decision-making.

3.3 Communications infrastructure in Queensland

In January 2011, major flooding occurred in the Brisbane River catchment, most severely in the Lockyer Creek and the Bremer River catchments. The flooding caused the loss of 23 lives in the Lockyer Valley, and thousands of properties were inundated in metropolitan Brisbane and its surrounds. Insurers received some 56,200 claims, with payouts totalling $2.55 billion (2011 prices).

The flooding had a major impact on telecommunications infrastructure owned and operated by Optus. Mobile services began to experience disruptions from 11 January in the Brisbane metropolitan area and were largely restored by 14 January. Some disruptions continued until 24 January, when services were fully restored.

This case study highlights the response from Optus and the potential benefits of resilience measures it has since adopted. It retrospectively analyses the cost of the event and examines the benefits in terms of costs that could be avoided through implementing resilience measures (that is, it assumes the economic costs of the flood could have been avoided). Like previous case studies, it illustrates the potential benefits of implementing additional resilience measures.

3.3.1 Optus' response to the Brisbane Floods

There were several of business challenges faced by Optus during the 2011 floods. The company responded to the crisis in two main phases.

Rescue and secure phase

Optus' telecommunications services played a key role in assisting with the immediate aftermath of the flooding. Optus joined the command centre set up by the Queensland Government to support the initial response efforts and help the government make more informed decisions. Optus supported rescues by identifying, through people's technology, who was missing and who was just out of touch. Following the crisis, Optus continued to be involved in the command centre.

Given the magnitude of the crisis, Optus needed to quickly shift and coordinate resources.
It mobilised a crisis committee to directly manage the response and implement the structured escalation system. Further, it used the National Operations Centre to coordinate on-the-ground actions.

The need for coordination was emphasised by three major events:

- **Flooding and loss of life in the Lockyer Valley** – Optus was involved in finding and helping survivors when communications were down. An important part of the initial response was establishing satellite mobile base stations at refuge centres to enable families to communicate. Optus also deployed crews into the valley to raise a hub site
- **Severing of underground cables** – Due to the violent movement of water and debris, a major underground line carrying all bandwidth and telephony in and out of Queensland was severed. To manage this, Optus redirected some of its usual traffic to other parts of the Optus network. In attending to the severed cable, staff members had to enter into a coronial area – that is, an area where a number of deceased people were located. This had a significant emotional impact on those employees
- **Brisbane central business district flooding** – Eventually the flood moved downstream to Brisbane city, which had a significant impact on Optus' infrastructure. At its peak on 11 January, 175 mobile nodes experienced outages and 150 remained down by 13 January.

Optus coordinated resources from across Queensland and other states to manage the crisis. For example, all installation engineers from NSW and Queensland were deployed to affected areas to restore telephony and fibre infrastructure. This had a flow-on effect for other parts of the Optus business, including customer service delays.

Restoration phase

The second phase of the crisis response involved re-establishing services. Optus deployed engineers and network experts to restore mobile nodes and optic fibres in affected areas. The restoration phase also involved restoring damage to backup systems, ensuring emotionally affected employees received support and implementing the resilience measures described in this report.

The communications outage placed lives and livelihoods at risk. While it did not lead to loss of life, it did create a critical and highly emotional situation. It had a major impact on families and communities unable to contact loved ones.

A community outpost staged at the local pub. The community of Murphy's Creek was isolated from all communications during the disaster so Optus deployed a SatCat mobile base station to provide communications and support for a number of weeks. *(Optus)*

Optus engaged the resources of a Helicopter Charter company to transport a 5km drum of cable to repair and reconnect the Optus Network as soon as the water receded. *(Optus)*

3.3.2 Implementation and cost of resilience measures

Optus implemented several resilience measures in response to the flood, including:

- Raising equipment rooms at low-lying flood-prone sites (six sites have been lifted above the one-in-100-year flood line)
- Moving alternating current (AC) power feeds to higher levels in buildings
- Improving the battery capacity of electricity main supply (from four hours to eight hours)
- Replanning critical radio links to build redundancy paths.

These resilience measures are designed to prevent outages on the mobile network in the event of a major flood similar to the one in 2011. Table 3.7 summarises the costs of each of these measures.

The total cost of the resilience measures is estimated at between $3.4 million and $5.4 million.

Table 3.7: Cost of Optus resilience measures

Measure	Cost per site	Number of sites affected	Total cost ($m)
Improving battery capacity	$5,000–$10,000	175	$0.88–$1.75
Raising equipment rooms	$50,000–$100,000	6	$0.30–$0.60
Moving AC power feeds to higher levels in buildings	$5,000–$10,000	175	$0.88–$1.75
Replanning critical radio links to build redundancy paths	$7,500	175	$1.31
Total			**$3.4 – $5.4**

Source: Optus

3.3.3 Potential benefits of the resilience measures

The potential benefits of implementing additional resilience measures are estimated in terms of the avoided replacement costs and the avoided lost economic surplus. It assumes that similar risks for this event apply in the future – that is, it is roughly a one-in-30-year event.

Avoided replacement costs

More resilient infrastructure is less likely to need replacement if a major flood occurs. This creates a benefit from avoiding the cost of replacement. According to Optus, the cost of replacing communications infrastructure after the 2011 floods was $1.1 million in the Brisbane metropolitan area.

Weighting these costs by the frequency of flooding (that is, 11 major floods in 171 years for Brisbane), and assuming a 3% discount rate, it is estimated the expected avoidable replacement costs for Brisbane could be about $70,000 per year or an expected cost of about $2.3 million in perpetuity.

Avoided lost economic surplus

The outage from the floods also resulted in lost economic surplus. This loss consists of: loss of customer capacity to communicate via Optus networks, and a loss of profits for Optus.

To calculate consumer surplus, two annual communication reports from the Australian Communications and Media Authority were used. These included an approach to estimate consumer surplus from telecommunications services and allowed us to make similar estimates for Optus customers in Brisbane.

To calculate producer surplus, it was assumed that this is represented by profits. According to IBISWorld (2015), 13% of telecommunications revenue is retained by businesses as profits. Weighting this profit by population share, it is estimated that Optus made about $200,000 of profit per day in Brisbane in 2010–11.

For each day the communications network was out of service, there was an estimated loss of about $800,000 in consumer surplus for Optus customers in Brisbane and $200,000 in profits for Optus per day. Assuming a three-day outage, this suggests a total loss of $3.1 million in economic surplus in 2011.

3.3.4 Summary

Overall, the benefits of resilient infrastructure implemented by Optus are estimated to be at least $4.2 million, compared to the costs of these measures which is between $3.4 million and $5.4 million. This suggests that, for the benefits to exceed the cost, the annual probability of a similar event must be greater than 2.4%, and above 3.9% if the costs are at the higher estimate. Table 3.8 presents a summary of the results.

This estimate is conservative, as it does not consider the avoided costs of managing an outage, the reduction in damages associated with early warning systems, or the avoided insured losses and social impacts. It also highlights that, though the costs are concentrated, the benefits are more widely spread – in this case most of the benefits flowed to users of the Optus mobile network.

Table 3.8: Costs and benefits of resilient communications infrastructure in Brisbane ($m)

	Benefits	Costs
Avoided replacement costs	$1.1	
Avoided lost economic surplus	$3.1	
Total avoided costs	**$4.2**	
Cost of resilience measures		**$3.4 – $5.4**
Risk threshold to break even		**2.4% –3.9%**

Source: Deloitte Access Economics (2016)

Box 10: Costs of managing an outage

By implementing more resilient infrastructure, Optus would also avoid the costs associated with managing a network outage.

According to a survey by Heavy Reading (2013), mobile operators spend about 1.5% of annual revenue on managing outages. In its sample, each operator reported five outages in a year, lasting between one and two hours. This suggests that, on average, each outage costs 0.3% of annual revenue.

The study looked at costs including:

- Suspension of the ability to capture revenue from a billable service
- Operational expenses to fix the problem (including staff overtime and impacts on other projects)
- Refunds to customers
- Subsequent increases in the rate of subscriber churn
- Forgoing future revenue due to damage to brand reputation
- Legal costs relating to meeting service-level agreements
- Contingency-related expenses.

However, it is unclear which of these costs are included in the Heavy Reading (2013) estimates.

A typical outage costs about 0.3% of annual revenue. The duration of the outage in 2011 was 72 hours and the Queensland floods were roughly a one-in-30-year event, thus the cost of managing the outage is $1.7 million in perpetuity.[10] This figure is likely to be larger however, as the outage lasted 72 hours, not between one and two hours as per the Heavy Reading study. Comparing this cost to the benefits listed above, the risk threshold is around 2.8% and as low as 1.7%. This equates to a one-in-50-year event.

This suggests that Optus' costs of managing this outage may be significantly larger than simply the lost producer surplus.

10. This figure apportions Optus' revenue by Brisbane's population, and is then weighted according to the frequency of the event. It assumes that each outage lasts between one and two hours.

3.3.5 Lessons learnt

Optus has spent approximately $1.2 billion annually on infrastructure since 2001. This makes it one of the largest ongoing investors in infrastructure nationally. Thus, Optus has a strong interest in ensuring infrastructure is resilient. Following the crisis, Optus noted a number of key lessons for infrastructure providers:

- **Ongoing coordination between assets is critical** – In managing the crisis, Optus experienced the interdependency of different types of infrastructure. For example, broadband services depend on a constant power source to function. Communications fibres are commonly attached to a bridge to cross a river, making communication services reliant on the bridge resilience. Thus, it is important to consider resilience from a holistic perspective
- **Proactively plan for resilience** – As climate risks escalate, the frequency of natural disasters will increase. Natural disasters significantly drain company resources, with flow-on effects for service delivery. Therefore, it is increasingly important to proactively plan for them. Optus is now working with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and using its climate models to revise engineering specifications to better reflect the increased risk of natural disasters
- **Raise the awareness of other utility providers and governments** – Given the increased interdependency of infrastructure providers, it is important that all stakeholders understand the benefits of resilience and the risks of not adopting resilience measures.

3.4 Summary

The case studies highlight the potential benefits of adopting resilience measures, if they are implemented correctly. However, careful analysis of the risks associated with the region and the potential resilience options is required.

Overall, the case studies suggest that:

- **There is a need to thoroughly analyse the natural disaster risks associated with new infrastructure projects.** This should occur before the infrastructure is constructed since poor decision-making can result in costly repairs and/or retrofits. This is highlighted by the Emile Serisier Bridge case study
- **Careful analysis is needed to ensure optimal decisions.** The Tatong bushfire case study shows that, while putting electricity lines underground across the whole region is costly, implementing resilience measures in specific locations where risk is concentrated may ensure that the benefits exceed the costs
- **It is important to analyse the available options to improve resilience following a natural disaster.** Assuming the current measures are effective, the communications case study indicates the resilience measures Optus adopted will yield significant benefits
- **Investors must carefully consider uncertainty surrounding costs, benefits and the probability of natural disasters.** These play important roles in determining the feasibility of a resilience measure.

The case studies suggest there are significant economic benefits associated with resilience measures. The difficulty lies in appropriately assessing hazard risks and in evaluating cost-effective options to enhance resilience in terms of avoided disaster costs.

While there is a clear case for resilience, there is also a need to improve the availability of information and best practice approaches and to expand technical capabilities for considering resilience in infrastructure decision-making. Further, policies must be changed to develop and implement appropriate incentives for investors to evaluate resilience options, even when they may have a greater initial cost. This could be inclusion of criteria to demonstrate the consideration of resilience within project appraisal frameworks, or funding mechanisms that recognise the distribution of resilience benefits to the broader community.