Australian climate extremes and building transport network resilience

By Marlies Barendrecht, Kristen MacAskill, Catherine Tilley

Abstract: Flooding can test systems to their limits. This case study explores the process of flood recovery and how the socio-technical system surrounding transport infrastructure management changes over time. It investigates the role of the Queensland Reconstruction Authority (QRA) in advancing the resilience of the road network in Queensland, Australia. The evolution of resilience management of the road network can be examined through changes in the boundaries of the QRA's remit. Initially the QRA's system of intervention consisted mainly of the road network assets. Expert engineering knowledge was necessary to manage the recovery programme and develop solutions for reconstruction. Over 10 years, the QRA's system of intervention expanded to include the environment (i.e. considering future threat of natural hazards) and communities. This evolution highlights that there are not always clear technical solutions to effectively address flood risk. The QRA has worked to manage this system and its resilience by: 1) developing both explicit knowledge (design standards and evidence of flood damage) and tacit knowledge (managing social relationships); 2) building close relationships with local governments as well as state and federal government; and, 3) removing barriers to resilience building through advocating for changes in funding arrangements.

Contents

Tags: Resilience, Road network, Flood risk, Technical and adaptive change

List of acronyms

DTMR
Department of Transport and Main Roads

DRFA
Disaster Recovery Funding Arrangements

NDRRA
Natural Disaster Relief and Recovery Arrangements

QRA
Queensland Reconstruction Authority

UNISDR
United Nations International Strategy for Disaster Reduction

1. Introduction

1.1. The problem

Transport infrastructure is an intrinsic part of society, providing a critical base for economic and social activity. Regions around the world face increasing exposure to major catastrophe when road infrastructure assets cannot provide expected levels of service. Disasters result from systems being stressed beyond their capacity to cope with the conditions faced, for example, coping with extreme weather. They lay bare the limits of safety that are consciously or unconsciously designed into our infrastructure systems. These limits reflect the assumptions that existed at the time the infrastructure was built. For example, asset design assumptions based on past climate might not reflect the likelihood of future disasters. Expanding economic activity is increasingly reliant on global supply chains, just-in-time delivery, and systems with little redundancy, meaning that the impact of disasters is more significant than when the network was originally built.

However, while disasters are in themselves undesirable, they often provide an opportunity to learn and improve practices and policies by surfacing these fallible assumptions. By better understanding disaster recovery, we can create new insights into how safety (including dynamic concepts of safety such as resilience) can be improved not just within the physical infrastructure system itself, but the communities these systems serve. The UN's roadmap for developing safer communities – the Sendai Framework for Disaster Risk Reduction – emphasises the importance of building resilience. It promotes the concept of 'build back better' which captures the idea that disaster recovery should not just focus on rebuilding to pre-disaster conditions, but to make changes to reduce the impact of future shocks and stresses.

Infrastructure system resilience requires not just engineering design expertise, but also an understanding of exposure to hazards, how that exposure is changing, how the rules governing decisions determine certain outcomes, and clarity of purpose of the system. In the context of managing transport networks in response to major flooding, for example, this implies that the reconstruction process should accommodate how to reduce the impact of damage of similar weather conditions in the future. In theory, the concepts of resilience and build back better have been incorporated into international guidance as an essential to the process of disaster recovery (Sendai Framework for Disaster Risk Reduction 2015–2030), particularly in the wake of the COVID-19 pandemic. However, in practice, reconstruction is not simply a technical problem: there are significant barriers to implementation. Availability of funding is the most obvious one but there are wider governance, leadership, and capacity considerations that also have a major influence.

This case study focuses on the implications of these factors for transport infrastructure, with a primary focus on roads. It will explore the process of flood recovery and how the socio-technical system surrounding transport infrastructure management changes over time. Through this, it will present the need to adopt a wider systems approach to safety in addition to more traditional engineering concepts of safety. While systems thinking has been incorporated into transport safety in recent decades, this case takes the concept further. It adopts a socio-technical systems perspective that considers the criticality of the service provided: community survivability and resilience is fundamentally linked to the availability and functioning of transport connections.

Australia often hits global news headlines with climate extremes – droughts, fires, and floods. Extended drought in the early 2000s led to major investment in water treatment and recycling systems. This period was immediately followed by major flooding in 2010–11. The extent of damage caused by this flooding resulted in the establishment of the QRA to fill a major capacity gap for the management of a state-wide reconstruction process. The establishment and evolution of the role of the QRA provides a case for exploring the evolution and advancement of disaster risk governance and the implications for how critical transport assets are managed.

1.2. Methodology

This case study is not about analysing one particular safety incident. Instead, we explore a series of major flood events over time and the impact that this has had on the evolution of disaster risk governance in Queensland. We started with a review of the wider literature for commentary on infrastructure investment and design, focusing on managing exposure of transport infrastructure to extreme events and climate change risk (identifying

implications for the safety and vulnerability of communities). This was not a comprehensive survey but focused on literature related to the Queensland case or exceptional coverage of the core themes of infrastructure resilience and transport system safety. This also included coverage of Australian recovery legislation, guidance, regulations, recent audits, and reviews with respect to infrastructure funding and design rules as well as disaster management and recovery. This review led to an initial narrative on the evolution of disaster risk governance in Queensland and helped formulate our interview topics.

We then interviewed key stakeholders at the QRA, Queensland Department of Transport and Main Roads (DTMR: the state-level road authority), as well as local mayors and senior engineers at shire/regional councils who have a role in the design and implementation of road infrastructure and/or disaster risk management. Nine interviews were held with 11 senior practitioners across these stakeholder groups (**Table 1**) to ground the case in experiential insights and examples to both verify and expand the narrative. The interviewees were sent an information sheet with several broad questions (see Appendix A); the interviews were relatively open in exploring the topics of most relevance to each interviewee's expertise.

The concepts of safety, resilience, and systems thinking were applied as the overall critical lens through which we analyse the case. Section 2.1 sets out the context of these concepts and the relationships across them.

1.3. Case structure

In Section 2.1 we outline key concepts that underpin the case: resilience, safety, and the consideration of different system boundaries in the management of road infrastructure safety. Section 2.2 provides an overview of the case study context, outlining key events over time and providing an overview of the evolution in disaster risk management capacity. Key to this is the change in the system of focus over time and the development of governance arrangements in an attempt to move from a reactive response to stressors (i.e., major flood events) to incorporate more pre-emptive preparation. Section 3 provides a more detailed narrative of the case, piecing together the developments over time, exploring why certain key developments happened at certain points in time. Then in Section 4 the case is summarised using three core themes that capture important developments and tipping points in the story. Section 5 provides an overview of the lessons learned and their wider applicability.

Although many stakeholders were involved (and interviewed for the case study), the main narrative focuses on the role of the QRA because of their central role in the systemic change in governance. However, we draw on comments and observations made by interviewees from local government and the DTMR.

Interviewee description	Interview code
QRA Executive	INT1
QRA Executive	INT2
Regional Mayor	INT3
Engineer of Regional Council	INT4
Shire Mayor	INT5
Shire Mayor	INT6
DTMR disaster recovery team (3 interviewees)	INT7
Engineer of Regional Council	INT8
Engineer of City Council	INT9

Table 1. Case study interviewees

2. Key concepts underpinning the case

2.1. Safety, resilience, and systems thinking

Road safety as a discipline has evolved alongside the development of modern road networks and motoring over the past century. Its core goal is to minimise injuries and fatalities caused by road accidents. Earlier underpinning philosophy of road safety tended to be reductionist, solely attributing fault of accidents to drivers using an otherwise well-designed and controlled system. More recent approaches account for contributing factors in the wider road environment, considering more systemic interplay of actions through vehicle manufacturing, law enforcement, land use, road design, and other road users.[1] Each of these areas have different levels of influence on the design of road networks and assets, as well as on the operational constraints on road use. However, the behaviour of individual road users and the reliance of communities on roads creates a complex socio-technical system that cannot be fully controlled.

There have been calls for even greater adoption of systems thinking in road safety (For example, Salmon et al. 2016, Shalom Hakkert & Gitelman 2015,

1 The Queensland DTMR adopts the broader systems approach (called the Safe Systems approach) in its road safety policy.

Naumann et al. 2020), but they all remain focused on the primary goal of reducing accidents on roads. This remains an important endeavour for stakeholders with control or influence over critical components of the road network. However, if we apply a broader perspective through considering a scenario where major parts of a road network are flooded, unusable, and communities are cut off, provision of safety becomes a different problem. In this context, safety can be thought of as not just a problem of minimising accidents and fatalities on the road network, but also managing the safety of communities when extreme events prevent normal service delivery – such as road access to a hospital. Safety then becomes closely related to the resilience of the road network and the broader social, economic, and technical system in which it sits.

This notion of resilience has proved to be a useful orienting concept across various disciplines – it has been adapted and extended over time. In the context of disaster risk management, the UNISDR defines resilience as:

> *"The ability of a system, community, or society exposed to hazards to resist, absorb, accommodate to, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions."* (UNISDR, 2009, p.24).

A seminal paper by Bruneau et al. (2003) on enhancing earthquake resilience of communities highlights that resilience is multidimensional both in terms of the properties of the system (including, robustness, redundancy, resourcefulness, and rapidity) and that there are different dimensions to consider (including, physical/technical, organisational, social, and economic). Later authors have suggested alternative dynamic capabilities such as graceful extensibility and sustained adaptability (see Woods 2015, Seager et al. 2017, Chester et al. 2019, Chester et al. 2021). Graceful extensibility denotes the ability of a system to cope with disturbances and changes that go just beyond the disturbances it was designed to withstand. Sustained adaptability relates to the capacity of a system to adapt to long-term changes. These are more nuanced terms for considering system features and capabilities. In general, there is agreement across various interpretations that resilience is not just a function of the physical qualities of a system. The management of the system and the wider context in which it operates also play an important role in a system's resilience. Thus, a safe and resilient system enables not only a good technical response to problems, but also an appropriate behavioural response. Given that roads exist to provide a service (for example, to bring someone or something from point a to point b), which enables other services, one might extend the boundaries beyond the physical assets and consider wider environmental and socio-technical aspects, which has been adopted to some extent in current road safety practice.

As the system boundaries are expanded the characteristics of the system change from a simple or complicated context to one that is more complex, as conceptualised by Snowden and Boone (2007) via the Cynefin framework.[2] The framework classifies systems according to their complexity. There are five classes: Simple (or Obvious), Complicated, Complex, Chaos and Disorder (see **Figure 1**). In a Simple or Complicated system context, there are solutions for a problem that should be relatively straightforward to identify given the information available and past experience, for example, the traditional design of a bridge or culvert.[3] As the system becomes Complex, its behaviour is determined by the interactions of its components and cannot be understood simply by understanding the physical characteristics of the individual components of the system. In a Complex system the outcome of interactions within the system is not always predictable or planned for. The appropriate management strategies emerge through responding to a changing situation instead of being designed *a priori*.

Linking this idea back to resilience (also considered in **Figure 1**), one might improve the resilience of a Simple or Complicated system by increasing its robustness to predictable events. A Complex system is inherently unpredictable, improving its resilience therefore must go beyond robustness to graceful extensibility and sustained adaptability, allowing the system to cope with, and adapt to, unforeseen events. This means expanding the focus to the organisational, social, and economic dimensions of the system, not only the technical or physical. Managing the resilience of the different types of systems requires a different approach. Adopting Heifetz and Linksey's (2002) framing of change: there is a difference between a 'technical change' that is to say, change within the existing system (for example, improving a road), and 'adaptive change', which is changing the system itself

2 The Cynefin framework is a descriptive rather than a diagnostic framework, helpful in this case for describing the evolution of decision-making in Queensland over time.

3 One might argue that no engineering design intervention falls within a 'simple' context because it requires a level of professional expertise to make a decision. We argue that that most basic interventions or decisions fall within this domain, supporting the position of Chester et al. (2019).

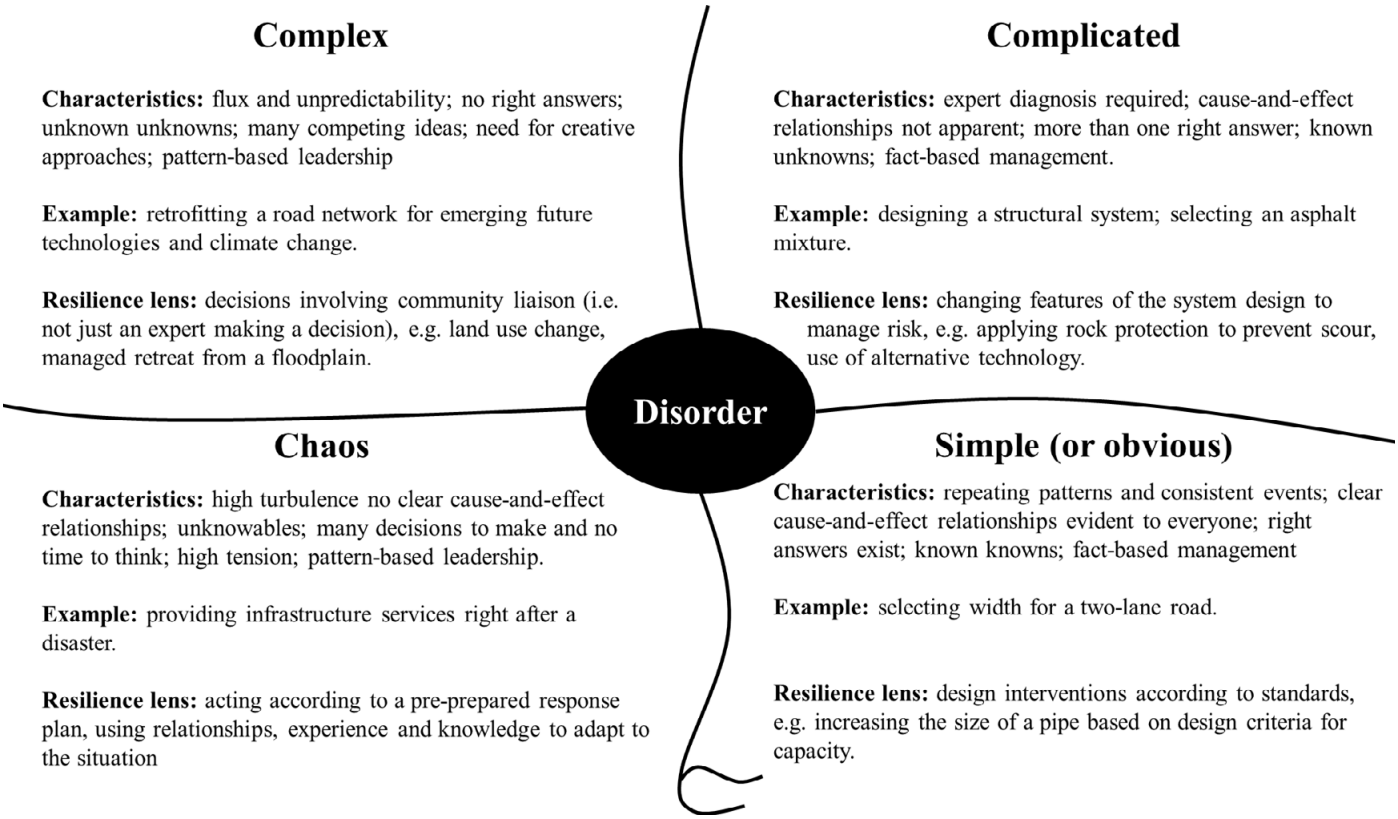


Figure 1: The Cynefin framework applied to road infrastructure decisions. Each domain has different characteristics and requires a different approach to management. Also, the approach to managing resilience varies depending on the domain. Adapted from Snowden and Boone (2007) and Chester et al. (2019), also based on the hierarchy of resilience measures presented by MacAskill & Guthrie (2015).

(for example, changing the way communities use a road).

2.2. Queensland transport infrastructure system – a decade of flooding

Queensland, Australia has a population of approximately 5 million people (Australian Bureau of Statistics, 2020a) and an area of 1.7 million square kilometres, over seven times the size of the United Kingdom. Of the total population of Queensland, 64% live in the (mainly coastal) cities and the rest in rural areas (Australian Bureau of Statistics, 2020b). The state has over 183,000 km of roads (DTMR, n.d.) of which 18% is managed by the state's DTMR (Queensland Government, n.d.) (see **Figure 2**).

The climate in Queensland varies from tropical to very dry and the state has a long record of droughts and floods. After a long period of drought, flood events in 2010–11 resulted in unprecedented damage of an estimated AU$ 15.7 B (approximately £8 B) across the state (World Bank and Queensland Reconstruction Authority, 2011). In response to this event the QRA was established as a temporary organisation to oversee the reconstruction process.

Over the last decade, the QRA's approach to its role has evolved. It started out by managing reconstruction projects, focusing on repair and returning the road network to a condition that resembled pre-disaster function. This was predominately driven by the rules surrounding the allocation of federal funding. Through the introduction of a build back better fund, the QRA's remit was expanded to allow greater scope for increasing robustness. The remit expanded further following the QRA's establishment as a permanent entity. It has since become more involved in community resilience-building initiatives. **Figure 3** provides an overview of the events and changes that have occurred in the system, as well as the developments in knowledge that were necessary to enable these changes. The evolution over time is presented in further detail in Section 3.

The development of activity can be characterised through changes in the system boundaries of the QRA's remit. Initially the system of intervention for the QRA consisted mainly of the road network assets. Following an initial period of Chaos in establishing the organisation amidst a response phase, we suggest the organisation settled into something that could be classified as a Complicated operating basis

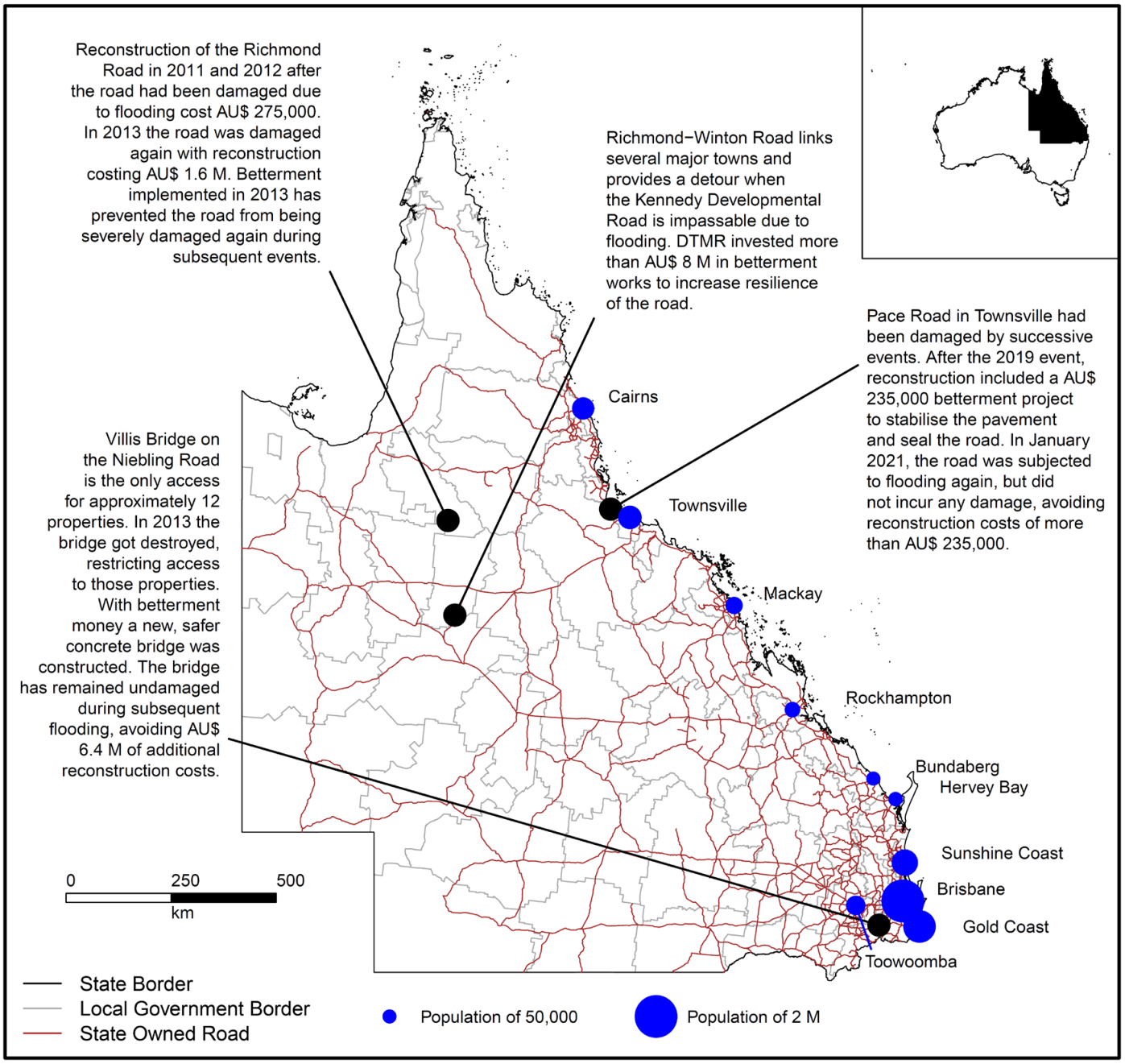


Figure 2: State-owned road network of Queensland, Australia.
Red lines represent state-owned roads. Grey lines represent local government borders. The 10 biggest cities/towns in Queensland are shown (with a population of 50,000 or higher). Annotations provide select examples of recovery interventions that included build back better (betterment) of the transport infrastructure system. For reference: AU$ 1 is approximately £ 0.54. Sources: State of Queensland (Department of Resources), 2021a (state road network); Australian Bureau of Statistics, 2011 (country borders); State of Queensland (Department of Resources), 2021b (state borders); State of Queensland (Department of Resources), 2021c (local government borders); QRA, n.d. a (betterment case studies).

(see **Figure 1**). Expert engineering knowledge was necessary to develop solutions for reconstruction, but the solutions were mainly technical interventions (for example, reinstating road pavement). Over 10 years the QRA's system of intervention has expanded to include wider considerations of the environment (that is, future threat of natural hazards) and communities. This involves a more Complex operational context that is difficult to manage and to track value for money (under traditional accounting/business case investment regimes). This requires different types of knowledge and acknowledges that there are not always clear technical solutions to problems.

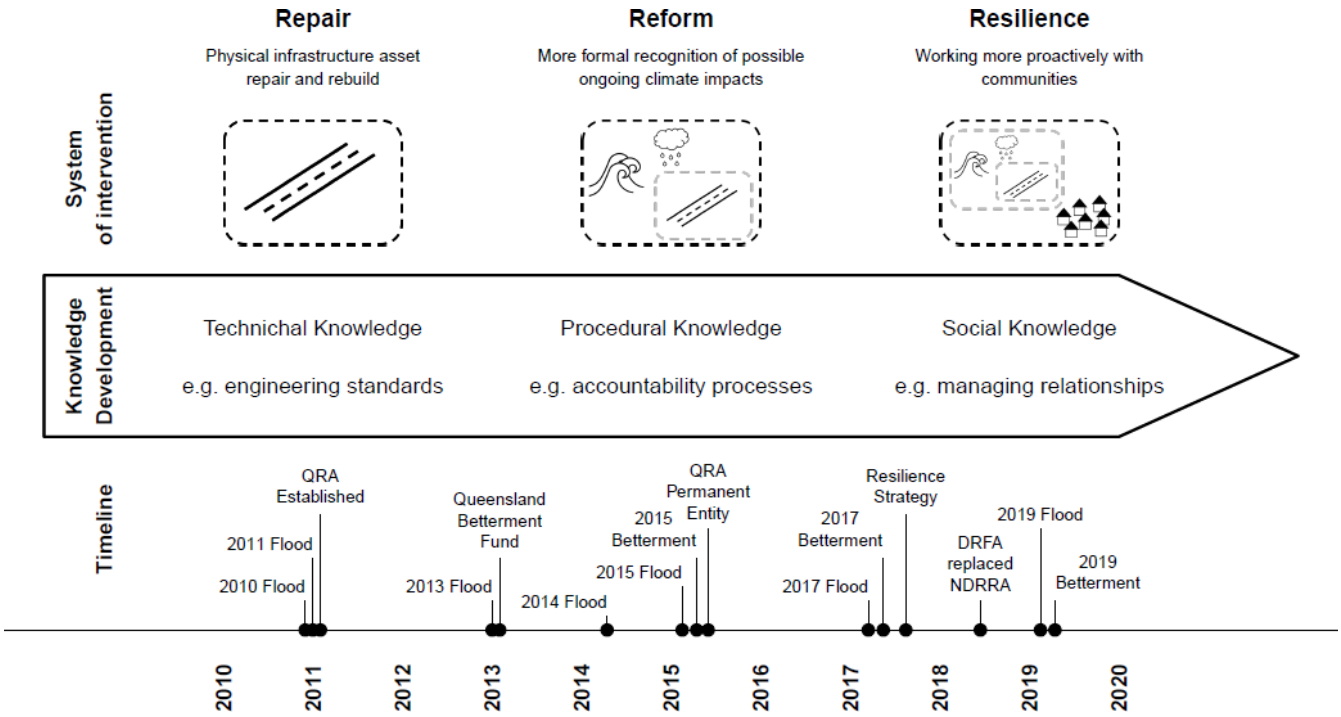


Figure 3: Timeline of events in Queensland that led to changes in the QRA's responsibilities. The figure shows the changes in the system encompassed by the QRA's remit, as well as the development of knowledge over the past decade. The timeline shows the most important events and only includes the most severe flood events. DRFA: Disaster Recovery Funding Arrangements, which replaced the NDRRA: Natural Disaster Relief and Recovery Arrangements.

3. Case analysis: The story of Queensland's management of transport infrastructure resilience

3.1. A wake up call

In 2010 Queensland was reminded of the devastating effects of flooding after a long period of drought. A series of flood events from 2010 to 2013 caused extensive damage to communities and the transport network. The floods of 2010 and 2011 damaged 9,170 kilometres of state owned roads and 89 state-owned culverts and bridges, 6,812 people were evacuated and 146,339 buildings were affected (QRA, 2011). Queensland's DTMR spent approximately AU$ 6.4 billion (approximately £ 3.4 B) on the reconstruction of Queensland's road network (DTMR, 2015). To finance rebuilding after the 2011 event DTMR started the Transport Network Reconstruction Programme, funded through the Natural Disaster Relief and Recovery Arrangements (NDRRA). According to this arrangement the federal government of Australia was responsible for funding up to 75% of the reconstruction costs, while the state of Queensland covered 25%. Road reconstruction funding fell under Category B of the NDRRA funding, which covered costs for restoration and replacement of essential public assets to pre-disaster standards.

The overwhelming extent of damage from the 2010–11 flood events led to the establishment of the QRA to oversee the appropriate allocation of funding for the Transport Network Reconstruction Programme. Initially, the QRA was created for two years, and it provided programme oversight of the reconstruction works (QRA, 2012). There were three main reasons for establishing the organisation. First, although previous recoveries had been led by the DTMR, it did not have the capacity to absorb this reconstruction as part of its normal operations and so engineering consultants were hired to provide programme management capacity. DTMR was responsible for the planning and delivery of reconstruction projects on the state road network, while local councils were responsible for the planning and delivery of reconstruction projects on the local roads. Funding for these projects, which came from the NDRRA, could be applied for through the QRA. Second, the QRA was established in a region that had been focused on managing an extended drought. Disaster reconstruction management at the time was fragmented and spread out across different government agencies. It was recognised that the existing arrangements were inefficient for managing large-scale recovery. Finally, in the years leading up to 2011, projects funded under the NDRRA had failed audit. Many claims made by

local governments were deemed ineligible for compensation because they did not provide the necessary evidence of pre-disaster conditions and the related post-disaster reconstruction works (Queensland Audit Office, 2013, p. 4–5). This showed signs of a coordination issue even before the major events in 2010–11.

The QRA faced the challenge of coordination and developing administrative processes under the responsibility of one agency. Specifically, it had to manage the liaison with national, state, and local government. It designed coordination mechanisms with the DTMR and with local governments that were based on knowledge sharing both through formal structures (such as frameworks and databases) and social ones (such as liaison networks).

This was significant for the DTMR because the unprecedented scale of the reconstruction meant that they were unprepared and had to learn on-the-go. The experience led them to establish a permanent programme for natural disasters. A team of about 10 staff act as a liaison between the QRA and DTMR and assists DTMR across its departments with reconstruction works and promoting resilience building. While projects since the 2010–11 recovery effort have been of a smaller scale (an average of approximately AU$ 100 million annually), the existence of a permanent disaster management team means DTMR can now upscale in case of another major event. This helps retain knowledge within the organisation and the team can easily instruct new staff who can be brought onboard quickly (INT7). This learning has improved the operational resilience of DTMR, so it is better able to cope with both smaller and bigger disasters.

A part of DTMR's Natural Disaster Programme is the development of design guidelines for reconstruction[4]. These guidelines were first created after the 2010–11 floods and have been kept updated. They not only include design guidelines but also funding eligibility guidelines. For each type of structure, the guidelines provide detailed information on standard design, resilience improvements, complementary works, and how these aspects can be funded (i.e., if works are eligible for funding through the DRFA or whether extra funding must come from within DTMR). These guidelines ensure that assets are built back better where possible and enable a continued improvement of the resilience of the road network.

In addition, the QRA had to assist local governments who did not have the financial, delivery, and management capacities to deal with reconstruction on the scale needed to recover after the 2011 flooding:

> *"I can't remember the exact figures, but it was somewhere between 85 and 110 million dollars [of] damage from 2013 alone, which for us is a big deal. So [in] relative terms, for us our entire capital budget for roads, drainage, footpath infrastructure is typically in the order of 28 to 35 million dollars annually. So, we were dealing with an event that was three to four times that in a single hit. And that scale of infrastructure delivery was extraordinarily challenging."* (INT4)

To manage this large programme and harmonise the approach to reconstruction, the QRA developed frameworks to assess projects and allocate funding. Over time, online platforms were developed to manage and track the whole reconstruction process[5]. The process included a requirement that funding requests included clear evidence of the state of an asset before and after the flood event. Data collected then began to develop into a database on the state of the transport network and its assets.

The QRA's work did not focus only on frameworks and databases. The QRA also established a regional liaison officer network to assist local councils with the reconstruction. The QRA had its team of engineers, roadbuilders, procurement advisers, and contract managers placed with local councils to advise and assist them where necessary (INT2). Through this network the QRA was able to better cater to the needs of each council.

From the start, the approach of setting up frameworks for project approval and establishing a network to assist local councils put the QRA in a role as a facilitator. Working within the legal space provided to them by the state and federal government, the QRA created the resources and the environment to assist local councils with reconstruction:

> *"Our local governments recognise we're there to help. We have boundaries about what assistance can be provided, and we will help them get into that space as quickly as possible."* (INT2)

All of this would not have been possible without leadership. The QRA established relationships with the state government and had a strong mandate for trying to improve processes (INT2). The CEO in charge of establishing the Authority had a strong vision, recognising that building trust with the different stakeholders was

4 https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/NDP-Design-and-Eligibility-Guidelines

5 https://www.qra.qld.gov.au/darm
https://www.qra.qld.gov.au/funding-programs/mars-portal-funding-program-applications

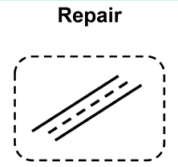
key. He highlights this in a recent interview:

> *"To achieve success for the QRA what was really important was to build trust, and build relationships, across all levels of government, and with the communities, so people didn't see us coming in and taking over and bullying them into a particular outcome. It was really more about 'How do we work with them to achieve the outcomes that they need to achieve but to support them?'"* (QRA, 2021a)

In parallel to the establishment of the QRA, the devastating flood events prompted a review of road infrastructure asset management and design standards. Management of road infrastructure assets typically proceeds on principles about managed deterioration and focuses on maintenance and rehabilitation rather than one-off major reconstruction[6]. This does not explicitly account for unplanned impacts such as the impact of major flood events. Aside from road assets such as bridges being destroyed by flooding, prolonged inundation of pavements increases deterioration and shortens their life span, increasing maintenance costs (Sultana et al. 2016). Reviews of the design of various types of assets that had been destroyed during the flood events showed shortcomings in both design guidelines and practices. Design standards change over time and many of the damaged bridges were built following old standards. Even if they had been upgraded to prevalent standards the design loads specified were lower than the flow velocities and debris loads that occurred during the events (Ezeajugh 2014, Pritchard 2013).

In the case of floodways, formal design guidelines did not exist and the guidelines that were available focused on flow velocity, with no account for debris flow (Lokuge et al. 2014).

Many of the proposed improvements could not be incorporated during reconstruction because the NDRRA only allowed for rebuilding assets to pre-disaster condition. The restrictions in funding arrangements hindered the ability to improve the robustness of the transport network. Since 2007 the NDRRA included a procedure for the application for extra funding, which provided a mechanism for additional funding for improvements. However, from 2007 to 2012 there was only one successful application for this fund (Productivity Commission, 2014). Within this framework each project had to be assessed and approved individually at a national level (INT1). This process was complicated and inflexible, discouraging application for betterment funding (Attorney-General's Department, 2015; Carroll, 2015; MacAskill 2016). In some cases, this resulted in assets being reconstructed to standards that were below the then prevalent design standard for that asset class given the legacy conditions (that is, rebuilding to current standards would effectively require making improvements to the asset). The total available funding was capped, rather than based on the total amount of reconstruction works necessary. This meant reconstruction projects had to be prioritised and the design criteria adapted to what was strictly necessary (MacAskill 2016).



To summarise, the severe events in 2010–11 triggered an increased awareness of flood risk. The QRA was established to harmonise the management of flood reconstruction and they implemented a framework to assess projects and allocate funding. Road infrastructure failures were evaluated and suggestions for improvements were made, but it proved difficult to adapt practice for reconstruction projects because of constraints in recovery funding arrangements. In the initial years, the QRA's focus was on repairing damaged assets and restoring the level of safety to the preflood level. The boundaries of the system it was concerned with were primarily placed around the road network assets itself. Following the initial chaotic situation, standard protocols soon emerged. The QRA's decision-making became more established in the complicated domain, predominantly reconstructing assets to prior as-built standards.

3.2. Reconstructing the same road over and over

With the continued occurrence of flood events during the wet season, the region began to encounter the need for repeated reconstruction of infrastructure assets (QRA, 2015). The January 2013 flood event caused damage to several infrastructure assets that had just been reconstructed. Given the reality of exposure to repeated damage, local communities called for improvements to reconstructed road assets:

> *"Okay well betterment's what we've always argued for, you know, why do we go back and fix that same Creek crossing it washes away every year? Let's put a bridge there or do something different."* (INT5)

In response to the calls for betterment from local councils, the

6 This state of practice will be generally recognised by infrastructure practitioners, but for reference it is discussed specifically in Beecroft et al. (2016).

QRA lobbied for and established the Queensland Betterment Fund together with the Queensland and Australian governments. The fund replaced the betterment provision of the NDRRA and provided a total of AU$ 80 M (approximately £ 42 M). A framework and estimates were agreed upon and the QRA was given the remit to manage the fund and approve projects under the framework (INT1). The betterment approach was based on the idea that building back better would save reconstruction and maintenance costs in the long term (Carroll 2015).

Local authorities that owned infrastructure assets damaged during the January 2013 events and that were activated for assistance under the NDRRA programme were eligible for betterment funding. These authorities could apply for extra funding from the Queensland Betterment Fund for assets that had been repeatedly damaged by flood events. Proposals for betterment of assets were assessed for completeness, eligibility, and value for money, including an analysis of both financial and non-financial benefits (Carroll 2015). It was important to prove the benefits of projects in terms of the asset's functioning and connectedness in a wider context to get funding for additional works (INT1). To allow for evidence-based funding requests and a smoother process of funding allocation, the QRA maintains an extensive database on the condition of transport infrastructure assets. It encourages local authorities to do the same. The benefits of this were highlighted by an interviewee:

> *"We have data to justify our claim in a particular corridor for what the loss has been. We don't have disputes over whether that was a 9-metre [road-width] seal or a 6-metre seal and what the orientation was."* (INT3)

Since its launch in 2013 there have been over 480 projects benefitting from betterment funding, amounting to a total of AU$ 240 M (QRA, n.d. b) across recovery programmes following flooding in 2013, 2015, 2017, and 2019. Examples of projects that are funded include the upgrading of pavements (**Figure 4**), construction of concrete floodways and the construction of improved bridges.

While betterment funding started to produce valuable results, this change did not apply to the DTMR until 2019. It had to fund betterment from its own funds, which in some cases was possible, but in other cases proved difficult because of the way funds are allocated within government agencies. Funding within DTMR is allocated to certain categories with different owners, for example, safety initiatives. It is difficult to re-allocate that money to, for example, spend it on betterment (INT7). This contributes to the limitations of the betterment programme.

Reform

The repeated occurrence of flood events created a case for accommodating building back better into reconstruction projects, accounting for future flood exposure and the robustness of the reconstructed solution. It triggered a revision of funding mechanisms to enable this. Specifically, it prompted a restructuring of funding arrangements for betterment, moving responsibility for processing claims from the federal government to the QRA (although funding still came from the state and federal

Figure 4: Aurukun Access Road (the only road link to and from the Arukun community). Left: Gravel road that was damaged in 2010, 2011, 2012, and 2013. Right: Bitumen seal instated in 2013 along a 10 km vulnerable section. This has since withstood impacts of eight natural hazard events (photos courtesy of the QRA).

governments). From 2013, the boundaries of the QRA's system of focus expanded to incorporate greater consideration of exposure to future flood events. This created a more complicated decision-making environment, with multiple solutions for rebuilding the assets (some with greater levels of safety incorporated than others, but often with cost implications).

3.3 Repair and prepare

Following the early flood events from 2010 to 2013 academic literature and public discourse shows evidence of a wider trend in calling for resilience building. As early as 2011, the *National Strategy for Disaster Resilience* acknowledged that increasing the resilience of transport infrastructure assets is linked to increasing community resilience. Increasing the safety of transport infrastructure during and after a flood event provides benefits to the community that go beyond potential economic benefits of more robust infrastructure (Council of Australian Governments 2011). Early studies of lessons learned emphasised the importance of infrastructure networks for emergency response and for creating resilient communities, particularly rural communities, calling for this to be incorporated in the design of road infrastructure (Pritchard 2013, Lokuge et al. 2014, Lokuge, and Setunge 2013).

This wider acknowledgement of the need for increasing community resilience was emphasised by a representative of a Queensland community. After they were hit by devastating floods in 2010–11 and 2013 they realised they needed to change their way of dealing with and preparing for flooding:

> *"We can't stop these floods. The scale of them is beyond the resources of government to deal with. So, we are a flood city. We're a River City. We'll forever remain that way. So, let's accept that and not pretend that someone is coming in on their white shiny horse [to] build … some kind of hard engineering solution here that's going to fix the problem. And working that through with the community to get that acceptance, [we can] then talk about: 'Well, what can we do to adapt or to reduce the consequence?' which was sort of the start of our journey on resilience."* (INT4)

The stories we have heard demonstrate that flood preparedness was not part of the mindset of many affected residents. There is particular concern for those who are less familiar with the history of their local region and its potential to flood. One council representative recounted a flood in 2009 and the unintended consequences of changes in community habits. It had become more common among community members to make frequent trips to buy fresh food rather than maintain stores at home. This proved to be a problem in the flood season when roads are cut off and access cannot be immediately restored. Houses are generally built on higher ground in the area, so people are safe in their homes, but they need to have supplies to survive. More established community members were used to this, but in 2009 new residents in the area were less prepared, requiring all kinds of supplies which placed heavier demands on response services:

> *"So it was either helicopter or nothing. And by the rules with flood damage, you're not supposed to be taking fresh food. You gotta take canned food, you gotta take flour, those sort of things, and that's fair enough. But these people weren't prepared, so we just broke the rules in 2009 and we took fresh milk out. Because, you know, one property we landed, it was four little kids, and three of them were naked. They had no nappies … which didn't worry anybody, they're all little kids, but you realised then the implication of the fast food, fast, you know, buy your bags and nappies, and not wash them. So, all those things are going through my mind and I'm thinking, well, we've got to do better than this."* (INT5)

Another example is the case of Scenic Rim, where community connectedness has historically been a source of community resilience, with neighbours provided each other advice and assistance. One interviewee described the advice he gave an incoming neighbour about flood risk on their land and implications for where a house should be sited. However, there is a feeling that general connectedness has reduced over time.

A small survey conducted in flood-affected suburbs in Brisbane in 2011 found that despite claims of awareness of flood risk there was a lack of preparedness (Box et al. 2016). One example of a reason for this lack of preparedness was that some residents assumed that the Wivenhoe Dam, which was built to help provide flood protection (following the experience of the 1974 Brisbane Flood), would provide protection. As a result of their study, Box et al. (2016) argued for better communication and support to help residents take on more personal responsibility for flood risk management.

This lack of preparedness at the community level is partly caused by how funding for disaster risk management is arranged. The NDRRA provided funding for community recovery, separate from the funding for the reconstruction of physical infrastructure. This included funding for clean-up, as well as recovery grants for businesses and communities. However, although the National Strategy for

Disaster Resilience encourages a better preparedness, these funding mechanisms are focused on relief and recovery (McGowan 2012, Dean 2015). This situation encourages the reliance on assistance in the recovery phase of an event instead of encouraging an increased preparedness and resilience of the community (Dean 2015).

> *"I think one of the biggest challenges every community faces is the expectation of people, and over time people continue to expect more and more, especially following a major event. Governments, as in the state and federal government, are quick to try and help without necessarily making people resilient."* (INT6)

An impeding factor, resulting from governmental financial strategies (and more general public and private investment in infrastructure), is the way budgets are planned. The costs of flood risk mitigation measures must be budgeted up-front with the immediate benefit unclear. A standard business case analysis does not necessarily place high value on the mitigation of what is perceived to be lower probability risk in the short term. This framing makes it comparatively unattractive to invest in mitigation, particularly when higher discount rates are applied. When spending money on disaster recovery on the other hand, it is immediately clear what the benefit is and governments are eager to be seen helping communities recover, even if it is not the most efficient way of spending money on disaster risk management (McGowan 2012). If political promises are made to do everything fast, that does not leave much room for doing things better. This was explained in conversation with a representative of a Queensland local council. While still in emergency-response mode a government minister arrived and declared that the community will see the fastest reconstruction in the history of the state:

> *"And that set a very difficult thing because it changed the conversation towards 'spend money quick' and the concept of value and betterment become harder because you can't just do all that and intertwine it and go: bang, here's the unicorn."* (INT4)

Besides financial aspects, another barrier to increasing flood resilience of communities was a poor understanding of the responsibilities of the different stakeholders involved in the different phases of flood risk management (Box et al. 2013). Many key stakeholders of flood risk management across Australia were not aware of the extent of their own and others' responsibilities, which shows that there was a need for a better definition of responsibilities and better communication between organisations (Box et al. 2013). McGowan (2012) notes that one of the recommendations from the Queensland Floods Commission of Inquiry (2012) exemplifies this. The report recommends this should be the responsibility of the government of Queensland or otherwise of the local councils, which does not improve clarity on who is responsible for the coordination and financing of flood risk mitigation activities.

The QRA had shown an ability to unify the approach to reconstruction across government agencies. In doing so it constructed a collaborative network across agencies and scales, supported by frameworks for the distribution of funding and responsibility. This enabled them to manage the reconstruction process and got them thinking about community resilience:

> *"What we did do right back then – which I think is sowing the seeds for our transition to more of a resilience focus – is that we essentially had the various elements of recovery, so the human, and social side, so the social systems, the natural systems, the transport, the built environment. We essentially, under the stewardship of the Director-General or the Secretary of each department, set up recovery groups within each of those elements. And all QRA did was coordinate the whole piece and that allowed us to really manage at a local level, at a state level and also Commonwealth level. It gave us the ability to manage the event much more effectively and we were the coordinating piece there."* (INT2)

This approach to strengthening the system included adding more complexity, transitioning from a focus on the complicated network of assets to the complex system of communities, natural systems, and infrastructure.

The experiences of 2010–2013 led to a growing call for increasing community resilience to flooding. However, in practice this was hindered by the available funding arrangements, as well as a lack of clarity on whose responsibility it is to build and fund community resilience. The QRA had proven to be successful at managing expectations, communication, distribution of funding, and collaboration between the different levels of government for reconstruction. While doing so, they also started to recognise the need, and lay

the foundations, for a wider approach to resilience building of the transport infrastructure system, including community resilience. In this period the QRA started to recognise the need for expanding the boundaries of its operation to include more focus on community intervention. However, in practice, its resilience building did not yet go much beyond improving the robustness of physical assets.

3.4. The Queensland Reconstruction Authority as a permanent entity

While overseeing the reconstruction works and coordinating the reconstruction funding, the QRA gained a vast amount of knowledge on reconstruction practices, funding mechanisms, community needs, and community engagement. With the number of disasters expected to increase due to climate change, the Queensland Government acknowledged the need for a more permanent agency in charge of dealing with disaster recovery (Robertson 2015). In addition, if reconstruction is managed by one organisation, this increases the ability to centrally coordinate funding, which reduces the risk of the Queensland Government failing audit (INT1).

A QRA Operational Review (see KPMG, 2015) highlighted that while its main role and activities had been focused on infrastructure and reconstruction, it had already undertaken activities outside its original scope to address gaps in the provision of services related to disaster risk management, such as flood plain mapping. While the QRA had the legislative power to do so, it was unclear what its responsibilities were in the mitigation and preparatory phase of disaster management. The report recognised the need for a wider approach to disaster risk management. According to the report, the QRA, with its connections across all levels of government and its experience and expertise, was in a good position to take up wider responsibilities for disaster risk management, including preparedness. To be able to do this, its responsibilities, and the responsibilities of other agencies needed to be clarified. In addition, the initial, temporary nature of the QRA meant that personnel had been drawn from various government agencies on a temporary basis. Retaining the knowledge and experience of these people as well as maintaining the connections with other agencies was seen as an important aspect for the future operation of the Authority. The report summarises:

> *"Given previous successes, the responsibilities and resources of the Authority could be augmented to target key areas and functions of disaster management where the QRA can add value. Its system-wide view of the disaster management lifecycle, independency as a statutory authority, and flexible operating model enable the QRA to provide unique insights into and support for activities across the span of the lifecycle, including prevention and preparation, particularly where cross-government coordination is required. However, the ability of the QRA to effectively deliver on its future responsibilities is dependent on establishing and communicating a clear mandate for the organisation across government within existing disaster management arrangements."* (KPMG 2015, p. 13)

The QRA had established the capacity to assist at both a local and state level and to move their resources around to accommodate the recovery and reconstruction needs after a big event (INT1). Internal interviewee accounts of the QRA's work suggests willingness to innovate and support new solutions:

> *"We've had a long record of, I suppose, just sort of thinking a little bit outside the square. And as I say, there are simple fit for purpose solutions. It can make big impacts. They stand out, you know, sort of: 'Wow there's a gap that we can fill, now let's come up with a solution for that.'"* (INT2)

A specific example involved supporting one council with the development of more flood resistant gravel mixes. These new gravel mixes are now also used by DTMR and are being marketed to other councils (INT3). As a state entity, the QRA was able to take on the associated risk of trying something new; subsequently the learning has been applied elsewhere.

In June 2015, the QRA Act was amended and the QRA became a permanent entity. Its responsibilities were expanded to include: "to plan for, coordinate and put in place measures to improve the resilience of communities for potential disaster events" (Queensland Reconstruction Authority Act, 2011). The organisation is now a mix of permanent and temporary staff and contractors. This allows them to scale when necessary. It also makes it possible to draw on expertise that is usually not readily available within government but that can be found in the private sector (INT1). The risk of losing institutional learning is somewhat mitigated through the presence of permanent staff (the DTMR now operates on a similar basis in maintaining its recovery capacity,).

To summarise, in 2015 the QRA

became a permanent entity, and its responsibilities were expanded to include improving community resilience. The prior operational experience since establishment in 2011 provided a platform for expanding to work more directly with communities and other stakeholders on community resilience projects. Here we can start to observe the adaptive capacity of the QRA as an organisation. The characteristics of the knowledge the QRA needed to perform its duties changed over time. They started with predominantly managing technical knowledge, codified in engineering standards, negotiated against funding availability. With its official role now including wider considerations of community resilience building, the QRA's system of focus becomes more complex, with increased scope for more social-oriented interventions.

3.5. An authority for disaster resilience

In taking on the additional responsibility of supporting resilience of communities, the QRA took three main steps: developing a new strategy; managing three distinct sets of funding arrangements; and continuing to build its network and processes. The QRA started by rewriting the *Queensland Strategy for Disaster Resilience* and aligning it with the Sendai Framework (QRA, 2017).[7] The process of developing the strategy was a collaborative effort, involving stakeholder consultation and local input:

> *"I guess if you go back to when we developed the* Queensland Strategy for Disaster Resilience*, we didn't just develop that strategy and roll it out. We actually started a community of practice, almost like a steering group – which included local representatives, NGOs, government from multiple levels as well – to actually hear from them about what's needed in our strategy and what actions should we collectively take to build our disaster resilience."* (INT1)

In 2018 the strategy was supplemented by an action plan: *Resilient Queensland 2018–21 Delivering the Queensland Strategy for Disaster Resilience* (QRA, 2018). This plan includes the development of locally led co-designed regional resilient strategies[8]. The QRA brought together councils to manage regions that are more defined by catchments rather than political boundaries. After pilots in the Burnett Catchment, Mary River Region, Fitzroy River Catchment, Brisbane River, and Central West Queensland, plans are now in development across all of Queensland (QRA, 2020). The role of the QRA is primarily to bring stakeholders together and make the process possible. This leads to very different plans for each region because each region has different needs:

> *"So each region was different, so each had a different message about what their vulnerabilities were, what the stresses were, and what they needed. So that builds us a picture across Queensland and some of it is infrastructure related, some of it is economic development, some of it is natural system related as well, and it builds up a big picture of your state and that way it will feed into the [future] state plan, as it were."* (INT2)

An exemplary case is the Central West pilot study, whose participants felt flooding could be a nuisance, but it is also a necessity because it brings them prosperity:

> *"The first engagement we had out West, one of the first things we were told is there's no such thing as a bad flood. There's an inconvenient flood, but floods bring prosperity and that we need / we must welcome that, manage them. Their greatest issue was not flooding. Their greatest issue was population decline and economic diversification and loss of knowledge from the land."* (INT1)

Another action is the preparation of local action plans which allow councils to prepare lists of actions and prioritise them to be prepared in case money becomes available (INT1). A side effect of this is that it may create more equality among councils who have different resources available (INT1).

Managing funding for recovery is a central part of this strategy, and by 2019, there were three distinct funding mechanisms. First, in 2018 the Disaster Recovery Funding Arrangements (DRFA) replaced the NDRRA (Australian Government Department of Home Affairs, 2018). Under the NDRRA system the Australian Government would reimburse the actual cost of rebuilding. Under the new arrangement the state is reimbursed for the estimated costs. The state takes on the risk of cost overrun, but if incurred costs are lower than the estimated costs, the state can retain the difference for investment in mitigation and resilience-building projects. This money is now being saved to spend on future resilience-building projects. The DRFA has been in effect since the 2019 floods, for which the final costs are not yet known. Estimated savings could be in the order of 10 to 20%. Like the NDRRA, the DRFA only provides funding for building back the same

7 The strategy revolves around four points that makes Queenslanders resilient: 1) "we understand the potential disaster risks we face" 2) "we work together to better manage disaster risk" 3) "we seek new opportunities to reduce disaster risk"4) "we continually improve how we prepare for, respond to and recover from disasters" (QRA, 2017).

8 https://www.qra.qld.gov.au/regional-resilience-strategies

without betterment. However, in the future, this new arrangement would provide almost annual savings that can be used to fund resilience projects (INT1).

To avoid artificial inflation of estimated construction costs the QRA implemented a benchmarking process for cost estimation. The QRA provides a treatment guide for common treatments (QRA, 2021b) and provides benchmark rates for each of these treatments for each of the 77 local governments. These standard treatments and benchmark rates allow for consistent cost estimates for projects funded under the DRFA. Cost estimates consist of three parts: 1) Base Estimate, which has the components Client Costs (Investigations and Design and Project Management) and Construction Costs; 2) Contingency, this accounts for the risk; 3) Escalation, which accounts for changes in costs during the project period (QRA, personal communication, 31 August 2021).

One way to save costs and deliver below the benchmark rate is for the local councils to deliver the reconstruction work themselves, using their own workforce. The use of council workforce, plant, and equipment often results in efficiencies through savings in mobilisation, reduced duration, or workers with greater familiarity of the assets, material, and water sources, as well as a general lower rate incurred when compared to contracted labour. In many cases this is already normal practice. Local councils have their own workforce for general maintenance that can also be used for reconstruction. DTMR also has contracts with the local councils as custodians for the maintenance and reconstruction of state-owned roads (INT7). There is a difference between work that can be funded through the DRFA and work that has to be funded through the council's own budget. Projects are only eligible for DRFA funding if the council can prove the damage is due to the flood event. This is also why the QRA encourages the local governments to maintain a database on the state of their road assets.

Another option to save costs is by managing the contingencies (INT1, INT7). There is a certain percentage of money allocated to risk, which is not always used up. The savings of all projects within Queensland are managed by the QRA and can be used for future projects.

The second funding mechanism is annual funding available for resilience building from a national partnership agreement on disaster risk reduction (Queensland Government 2021). This is divided among states according to population and Queensland receives 23% of that funding (INT1). This funding is matched and topped up by the Queensland Government and is used for the Queensland Resilience and Risk Reduction Fund. Local governments, NGOs, and state agencies can apply for the fund. In 2021 there was AU$ 19.1 M (approximately £10 M) available, but requests were made for over AU$ 164 M (approximately £87 M) (INT1). So, the demand for funding is much higher than the availability. There is a range of projects that are funded through this programme, such as road works, evacuation planning, flood studies and emergency power supply (QRA, n.d. c).

The third funding mechanism is 'Get Ready Queensland', which allows the QRA to run a programme on implementing initiatives to improve resilience in Queensland. Councils are allocated a share in $2 million in annual funding for their preparedness activities. One example of a successful use of this funding is by the Burdekin Shire Council, which collaborated with neighbouring councils to create a series of videos on getting ready for disasters[9]. Another Burdekin Council initiative funded through 'Get Ready Queensland' is the construction of an *Emergency Action Guide* that was posted to every resident in the shire (INT6). Another council runs TV ads on the local news channel at the start of each flood season. These ads inform people of how to prepare for flooding and what to do in case of a flood event (INT4).

As well as managing these three distinct funding mechanisms, the QRA maintains its network and relationships with local governments. In a complex system, such as this, there is often tension between the central and local parts of the system. Many of our respondents indicated that the QRA aims to use local knowledge and to assist the local governments while leaving local governments in charge. Some respondents indicated that while it is good to have a QRA officer appointed to their region, the officers – being based in Brisbane – are not embedded in the local region and this limits their familiarity with the local context. The QRA also continues to improve procedures for project approval. Some local governments indicated that the collection of data to underpin their funding claims has helped to make access to funds possible. However, some respondents also mentioned that extra resourcing is required to support the additional bureaucracy, which had not been the case for earlier claims for NDRRA reimbursement. While the QRA processes provide increased transparency in the allocation of funds, the processes are not *always* perceived as value-adding at a local level.

In recognition of the QRA's legislative responsibility to coordinate the development and implementation of whole-of-government policies for managing

9 https://www.burdekin.qld.gov.au/emergency-management

flood risks, the QRA developed the *Queensland Flood Risk Management Framework* (the Framework) (QRA, 2021c), which sets the direction for flood risk management in the state. The Framework provides clarity and understanding of expectations, outlines responsibilities of policy settings, and guides, and supports decision-making by local governments. The QRA has the coordinating role in implementing the Framework. This coordination role requires key state agencies to lead the development and implementation of their respective activities to support decision-making by local governments.

The QRA Act 2011 was amended for the second time in 2019 to reflect the Authority's roles and responsibilities for all hazards as well as their leading role in resilience. The amendment includes a detailed part on community resilience, which both reflects the recognition of the need for a holistic approach to disaster resilience, as well as the important role the QRA plays in the coordination of whole-of-government flood risk management policies. This Section has detailed the expanded focus of the QRA in coordinating wider preparedness and socially oriented planning activity. This has involved convening stakeholders in new forums and experimentation in the development of new strategies.

4. Discussion & learning

Section 3 outlined the evolution of resilience management of transport infrastructure in Queensland and the role of the QRA. In this Section we examine three key themes in this story. While these themes can be considered separately, they are closely linked and their combination has been important for Queensland's path to improving its disaster resilience. Key learning from this case can be drawn through these themes.

4.1. The Queensland Reconstruction Authority as a resilience broker

The formation of the QRA led to a process of transition in managing checks and balances of disaster recovery at a local, state, and national level. The QRA had to engage the local governments to help them in that transition and at the same time had to show the Australian Government that they knew what they were doing (INT2). From the start the QRA worked to build relationships and trust with the local, regional, and national levels of government. These relationships allowed them to act as a broker for building resilience in two directions. From the top down, they receive lump funding from the national and state government, who placed trust the QRA to distribute that funding to local governments in an efficient and effective manner. From the bottom up, the local councils appeal to the QRA for changes in policies and funding arrangements. They share their needs with the QRA and the QRA can advocate for change at a regional and national level. One example is the Betterment Fund, which was called for by local governments, advocated for by the QRA and eventually funded by the Australian and Queensland Governments.

The ability of the QRA to act as a resilience broker is based on these key characteristics of the QRA as an organisation. It:

1. Has a mix of permanent employees and temporary employees from government departments and contractors. This means the QRA can draw upon knowledge from both the public and private sector and distribute that knowledge to local governments, when and where needed. It can scale up and down and it is flexible in its operation.
2. Facilitates the process of resilience building by bringing people together, expanding on local discussions to consider resilience for a region as a whole (INT2). They do this at a local level when facilitating the creation of local action plans and at a regional level through the development of regional resilience strategies. They aim to expand this to a state level (INT2).
3. Has the capacity to take on risks for certain initiatives where there are potential wider benefits through the learning gained. Together with (and driven by) local councils, the QRA facilitates the implementation of new plans and new solutions. This has been aided by the support of the state and national governments.
4. The QRA has demonstrated the ability to operate within the legal bounds and evidence-base requirements. At the same time, they have built relationships with the local governments, allowing them to implement new projects and ideas with their cooperation.

This is not always a smooth relationship. The processes to ensure effective spending that were introduced by the QRA can be perceived as added bureaucracy that the local governments did not have to deal with before when managing flood repairs. While local government representatives express their appreciation of their relationship with the QRA there is also some discontent. This is associated with (A) the added the burden of processes developed for claiming compensation and (B) that local coordination does not extend to established local presence of the QRA in more remote regions.

Over time the QRA's remit expanded to address a broader set of issues beyond the initial mandate of recovery programme coordination. The developments were the result of repeated experience of flooding and the associated learning and capacity building that resulted from that. The repeated experience also provided the political will to look for more holistic approaches towards the management of flood risk.

4.2. Funding arrangements

Recovering from a severe flood event may require redistribution of money across different levels of government as the costs can be well beyond a local government's financial capacity to manage. This is where special recovery financial mechanisms come into play, often involving national, and state government subsidy of local costs. There are several ways in which the availability of funding and the arrangements surrounding the distribution of funding can hinder or enable resilience building.

One of the biggest problems in building a resilient system was that the main recovery funding provision in Queensland did not, until recently, provide for betterment, and a separate line of funding for betterment was practically inaccessible. This limited the options for improving the robustness of assets when the QRA set out to manage reconstruction after the 2010–11 floods. However, building on the experiences of managing repeated flooding, it was able to negotiate a new funding mechanism. From 2013 onwards the Queensland Betterment Fund allowed for 'building back better' by increasing the robustness of infrastructure assets with respect to flooding. While the purpose of the new DRFA introduced in 2018 is to enable recovery and reconstruction, it provides an opportunity for reconstruction programme savings to be spent on other preparedness and resilience-building initiatives.

The joint national and state funding programme can also provide a boost to the local economy. Allowing local councils implement the reconstruction work can result in efficiencies and under the new DRFA can be reinvested in the future for resilience building. In other words: paying the local government to do the work and thereby redistributing money to lower-level government is resulting in savings that can be spent on other projects.

A related financial factor is the capacity of local councils to invest early to mitigate flood risk. It is generally accepted as impractical to attempt to engineer a solution to fully prevent flood damage and achieve an absolute level of safety. Instead, there is an acceptance of the need for communities to cope with some level of flooding. As highlighted in Sections 3.3 and 3.5 the local councils recognise the need for improving community resilience and the funding made available for these purposes (via the QRA's wider resilience agenda) has been used for a variety of information campaigns.

This case study has shown that in the short term, revising funding arrangements can help remove barriers to resilience building. This has been implemented with the aid of and under the supervision of the QRA. However, limitations remain and there is ongoing debate over finding a balance in investing across mitigation, preparedness, and recovery. The benefits of resilience building are not easily captured in standard cost-benefit analysis processes.

4.3. Explicit and tacit knowledge

One of the key capabilities that the QRA has developed over the past decade is knowledge acquisition. Here we make a distinction between two types of knowledge the QRA has gathered and developed: explicit knowledge and tacit knowledge.

Firstly, the QRA has accumulated extensive explicit knowledge on the state of the road transport network. It has set up a database containing data gathered through local councils and the DTMR. This has helped resilience building in Queensland in several ways. It provides evidence for funding claims made by these agencies, enabling more transparent claims management. It also provides the QRA with the evidence to make a case for changes in funding arrangements, such as in the case of the Queensland Betterment Fund. Finally, the database allows for a more comprehensive analysis of the state of the transport network than existed before. This can assist in finding vulnerable spots (for example, identifying a frequently destroyed road that is the single access road to a remote area).

Secondly, the QRA has developed their tacit knowledge over time. Upon establishment in 2011, their focus was on repairing the road to the same standard as before the flood event. This required mainly technical knowledge on design standards and procedural knowledge regarding eligibility for compensation. They were responsible for overseeing the distribution of funding and as a result developed knowledge on how to effectively manage a state-wide programme (e.g., they developed and implemented processes for funding applications and their approval, including the development of online platforms). Throughout this process they developed new networks and became knowledgeable in managing the relationships with both local councils, state agencies, and the federal government. When their remit expanded to include community resilience, their experiential knowledge expanded to creating awareness raising campaigns and increasing community preparedness. This might be considered an exercise in sharing institutional knowledge at the user level. Thus, throughout the last decade the QRA acquired

knowledge with very different characteristics: from technical, to financial management, to social, and cultural.

4.4. Moving from a complicated to a complex system, punctuated with chaos

Linking back to the Cynefin framework (**Figure 1**) and the nature of system boundaries we can see that the QRA went from managing a Complicated system, where its system boundary was effectively placed around the road network, to managing a Complex system with the boundaries expanded to include climate and society.

In 2011 in the aftermath of the devastating flood events the QRA was established in a chaotic situation. At this point, predefined plans for managing the recovery were deficient and the QRA had to invent things on-the-go. It established procedures for the assessment of funding applications and set up a network for the assistance of local governments. In its early years of operation, the QRA's remit was the reconstruction of the road network and improvements to the resilience of the system were focused on increasing the robustness of the road network through betterment. During subsequent flood events, the response and reconstruction could then be managed through predefined protocols (for example, on gathering evidence on the damage to a road) and networks that were already in place. This is reflective of a move from a primarily reactive response to flooding to a more pre-emptive approach. Repeated events prompted further revision to a more adaptive approach to resilience management. The QRA widened its focus to include communities and their resilience, broadening its system boundaries to encompass a more complex system. In brief, the QRA managed to build resilience by adding, rather than removing, complexity.

5. Broader lessons for the management of complex systems

This case study calls for management approaches that go beyond a mindset of infrastructure as a complicated system, to an approach that engages more holistically with the complexity associated with the infrastructure system as a service. While the context for this case study is specific, there are some observations that may be generalisable to other organisations making changes to improve the resilience of socio-technical systems.

First, as we observe in Section 2.2, there are two distinct types of change within this case study: technical and adaptive (Heifetz & Linsky 2002). The QRA began their work facilitating technical changes such as improving the engineering standards and advocating to change eligibility requirements for rebuilding roads and bridges. Repeated flooding resulted in repeated damage, helping to create the business case for going beyond restoration to a former state (through technical repairs and treating the problem as Complicated). To build resilience in the system, the QRA had to take an adaptive approach to leadership – redefining and expanding its interventions in a way that is reflective of managing Complex problems. The QRA began this work as a perceived natural extension of their activity, although there was no formal mandate to do so. Their process of adaptive change had several distinctive features. First, there has been a multi-year process of engagement with local communities. This has allowed the QRA to build social connections across the system so that they can understand local needs and help build local capacity. Although there is some centralised expertise in the system, there is an important role for the local communities themselves to develop responses to flooding in their area. Second, the development of a database means that people from across the system have a shared way of seeing the network, despite hundreds of miles distance between stakeholders. This combination of activities means that the QRA has made the network socially denser – in effect, more complex – but at the same time has made it easier to understand its characteristics.

This added social complexity may seem counter intuitive. Often, added complexity in an organisation is seen as an additional cost: it can be seen as difficult to work with. Very often, we approach problems by simplifying them first – and yet that was clearly not the approach to change here. In this case, the complexity was helpful because it created value in parts of the system: for example, the closer relationships between the QRA and the communities enabled initially a more effective and timely allocation of funds, and later an ability to build capacity at local level. The relationship between the QRA and the Australian Government allowed the system to allocate funds in line with policy and with clear accountabilities. The QRA thus created a key mediating role, in a way creating more complexity in the network, but also adding the necessary capability to achieve wider success in disaster risk management.

While QRA was introduced as a new entity, it essentially slotted within the existing hierarchical governance system. The national and state government decided to make money available and exercised their power to give the QRA the mandate to distribute that money. The QRA's power to approve funding for local projects is bounded by the legislation and guidelines set within this system. In conclusion, the way in which the QRA worked to build resilience

to flooding in Queensland's road network was characterised by:

1. Creating a knowledge base to ensure that technical problems could be resolved to an appropriate standard, more consistently.
2. Adding density to the social fabric of the system as a way to 'shorten the distance' between national and state government and local communities, and to provide a way to transmit knowledge between groups. The QRA achieved this by building their network with the local communities early in the process and in parallel with the technical problem-solving.
3. Expanding its remit beyond an asset reconstruction programme to engaging in capacity building, despite the added complexity this brings to defining what success looks like for their own operations.
4. Managing the tensions that arise from differing interests and priorities across the system.

To do this, leaders need to be able to understand multiple points of view, to pay very close attention to stakeholders, and to be more invested in solving the problems rather than in 'being right'. These capabilities are relevant in a broad range of situations where the safety of a Complex system involves behavioural as well as technical components.

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KM = Project lead, support interviewer, initial research, final drafting

MB = Main researcher, lead interviewer, case development, image creation

CT = Support interviewer, final drafting

All authors were involved in conceptual development of the case.

Affiliations

Dr Kristen MacAskill, Assistant Professor, Department of Engineering, University of Cambridge

Dr Marlies Barendrecht, Research Associate. Formerly: Department of Engineering, University of Cambridge

Dr Catherine Tilley, Lecturer, Business Ethics & Sustainability, King's Business School, King's College London

Appendix A. Guidance for Interviewees

For Local Government Representatives

The QRA was established in 2011 to help oversee major flood reconstruction efforts. Over the years the aims and strategies of the QRA have expanded from managing a large reconstruction programme to working on improving community resilience. We are trying to better understand this evolution in the wider context of Queensland's preparedness for extreme weather events. We would like to hear your perspective on how your community's interactions with the QRA have changed over the years, and the role this has in your wider efforts to prepare for/recover from extreme events.

To help us understand this better, you could consider the following questions, which we anticipate guiding our discussion:

- Over the years 2010–2021 what were your key community needs during the recovery of flood events?
- What have been the biggest challenges for you locally in managing flood risk exposure?
- What has been learned (and implemented) to help prepare for future events?
- What do you consider are your key interactions with regional and/or state agencies for managing flood risk?

For QRA

The QRA has evolved significantly since it was established. We would like to understand this evolution from your direct experience. We are interested in how the aims and operation of the QRA changed over the last decade and how this was supported (or triggered) by changes in priorities, available funding, and the development of knowledge within the QRA. Areas we anticipate discussing are

- possible changes in the way stakeholders and projects are prioritised
- changes in available funding (e.g., where the funding comes from, what it can be used for and how this aligns with what the QRA and stakeholders hope to achieve)
- development in knowledge (e.g., development in technical guidelines, guidance on acceptable interventions, how to account for community perspectives and changes in procedures).

To help you prepare, you could consider the following questions: What were the critical turning points/developments in the organisation's history? What key events contributed to changes in the aims of the QRA? What has taken longer than you had hoped? Did anything develop faster than you had anticipated?

We have some examples in mind, but we are interested in your reflections and discussing what is most relevant to your experience before we steer the conversation in a certain direction. We are mindful of QRA's key achievements and highlights since 2011 (https://www.qra.qld.gov.au/news-and-case-studies/10-years-recovery-and-resilience), we'd like to explore the background behind some of them.

For DTMR

The QRA was established in 2011 to help oversee major flood reconstruction efforts. Over the years the aims and strategies of the QRA have expanded from managing a large reconstruction programme to working on betterment and improving community resilience. We are trying to better understand this evolution in the wider context of Queensland's preparedness for, and recovery from extreme weather events. We have already spoken to people at the QRA and to representatives of local communities. We would like to hear your perspective on how this change has affected the Department of Transport and Main Roads.

To help us understand this better, you could consider the following questions, which we anticipate guiding our discussion:

- Over the years 2010–2021, how has your approach to incorporating resilience in (re) construction planning changed?
- What have you learned about design standards and how has this new learning been incorporated into practice?
- How have processes developed to handle and manage reconstruction across the state?
- What do you consider are your key interactions with other state agencies as well as local agencies and communities?