SYNTHESIS SUMMARY 8

Infrastructure

Exposure to changes in climate threatens to impact the value and lifespan of some of Australia's most critical infrastructure with flow-on risks for communities and business.

NCCARF
National Climate Change Adaptation Research Facility

About this summary

About this series

Between 2008 and 2013, the Australian Government funded a large nationwide Adaptation Research Grant Program (the ARG Program) in climate change adaptation. The Program was managed by the National Climate Change Adaptation Research Facility (NCCARF). It resulted in over 100 research reports that delivered new knowledge on every aspect of adaptation. The aim of the Program was to help build a nation more resilient to the effects of climate change and better placed to take advantage of the opportunities.

This series of Synthesis Summaries is based on research findings from the ARG Program, augmented by relevant new literature and evidence from practitioners. The series seeks to deliver, in a short summary, some of the policy-relevant evidence from the research, in support of decision-making for climate change adaptation in Australia. It takes an approach identified through consultation with relevant stakeholders, which built understanding of the needs of the intended audience of policymakers, decision-makers and managers in the public and private sectors.

This summary deals with infrastructure. The opening pages provide the context, including the nature of climate change and its impacts on infrastructure ('Why we need to adapt'). This is followed by a more comprehensive synthesis of research findings around the impacts of climate change and adaptation responses for infrastructure ('The research base …'). The final section is a summary of how this new research knowledge might help address key adaptation policy challenges. This is informed by a workshop held with practitioners ('Evidence-based policy implications').

This Brief was prepared by Ron Cox, members of the Settlements and Infrastructure Network (ACCARNSI), and Sarah Boulter, Jean Palutikof and Ana Perez from NCCARF. It benefits from input on the policy challenges developed during a workshop held in Sydney in November 2016. The workshop was attended by practitioners, policymakers and managers from local and state government organisations, industry associations and the private sector.

The key research reports used to develop this summary are highlighted in Section 4. To see all reports from the ARG Program, please visit **www.nccarf.edu.au/adaptation-library.**

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Key findings

Australia's infrastructure represents a major economic investment and critical service to our communities and business. Infrastructure is exposed to the impacts of climate changes. Six principal adaptation challenges emerge from research evidence:

1. Address operational risks at the design phase

Consideration of operations and service delivery performance at the design phase can help reduce risks that arise in the future.

2. Consider maintenance and upgrading of existing infrastructure as adaptation options

Existing infrastructure may not be designed to deal with climate risks and asset owners may need to consider options of increased maintenance, retrofit or early replacement.

3. Manage the transition from past to future

Lack of climate resilience in existing infrastructure may put pressure on governments and asset owners to plan for upgrades and replacements, so that new developments are supported.

4. Communicate risks

Co-ordinated approaches by government departments responsible for planning and infrastructure are likely to improve communication and consistent messaging to ensure developers and asset managers understand the rationale of adaptation measures.

5. Build the business case

In building a business case it is important to consider both the monetary cost of climate impacts and non-monetary impacts (e.g. amenity and ecosystem costs). A focus solely on the economics of the business case runs the risk of making inappropriate decisions when faced with complex problems.

6. Support good decision-making

Achieving good decisions that represent a reasonable business case, provide good value for money and contribute to building community resilience is highly desirable. Governments and policy makers can support this through regulation, guidance and good communication.

1. Why we need to adapt

1.1 The climate context in relation to key infrastructure

The major changes in climate which are likely to impact key infrastructure are:

- sea-level rise
- increased frequency and duration of high temperatures leading to heatwaves and associated bushfires
- changes to seasonal and annual rainfalls affecting water resources
- increased intensity of extreme weather events (including cyclones) leading to higher storm-surge, winds, rainfall totals and flooding.

The worst-case potential impacts on physical infrastructure often arise from combinations of projected climate influenced events. Two key examples are the combined impact of drought, bushfires and extremes of temperature on energy generation and distribution systems[9]; and the combined impact of an extreme rainfall event with sea-level rise and storm surge on low-lying coastal infrastructure.[10,30]

Box 1: Defining infrastructure

Infrastructure assets are generally defined as stationary (or fixed) systems that serve defined communities, and where the systems are intended to be maintained indefinitely to a specified level of service by the continued replacement and refurbishment of their components. Infrastructure assets are typically found in:

- transport networks – e.g. roads, rail, ports, airports
- energy supply systems – e.g. gas, electricity, generation and transmission
- water utilities – e.g. water supply, sewerage systems
- stormwater management – e.g. flood detention systems, pipes
- community facilities – e.g. libraries, community halls, parks and recreation areas
- telecommunication networks – e.g. cables and towers.

1.2 Key risks

While all infrastructure sectors will be impacted by climate change to varying degrees, communities that use or are serviced by infrastructure are likely to feel the most significant effects. Loss of life is the most catastrophic outcome and has occurred, for example, when roads are washed out during floods. Loss of services and infrastructure failure during climate extremes also has the potential to incur significant financial costs. For the major transport organisation, Sydney Trains, Royal has calculated that the existing costs of extreme weather events represents approximately 1% of combined operational and maintenance costs each year for the organisation (Figure 2).[26] In addition, the existing estimated delay costs to customers from extreme weather events are estimated as more than $10 million per year.[26]

ATSE, Engineering the Future and NSW OEH all identified accounting for cross-sector interdependencies as the major climate change adaptation planning and management challenge for key infrastructure.[1,7,21] During the heatwave (and subsequent bushfires) that affected southern Australia in 2009, the interconnectedness of infrastructure and critical dependencies at both a system level (e.g. failure of generators and transmission lines in the electricity system) and operational level (e.g. failure of air conditioning units on trains interrupted train services) was demonstrated. This highlights the complex interdependencies between infrastructure sectors that lead to a high potential for cascading failure.

A number of analyses have highlighted the risk of 'total systems failure', with the electricity sector in particular highly vulnerable. Climate change is an additional pressure on these systems which are already stressed by the existing inadequacy of infrastructure, the need for investment in new infrastructure, policy uncertainty delaying new investment, and the use of past experience as the basis of future planning .[8,24] These risks are exacerbated by drought, extreme heat and bushfire – key climate change risks.

Infrastructure failures pose potential health impacts (e.g. failure of water or sewage treatment, failure of cooling/heating) and the risk of an interruption to emergency response, transportation and business.[24] There is also potential for a large financial cost resulting from disruption of businesses and repair of damage. In the case of the 2009 heatwave, the economic cost of power outages and disruption of public transport have been estimated at $800 million.[24]

All infrastructure sectors face risks and susceptibility under climate change (see Table 1).

Table 1: Sector-based risks of climate change to infrastructure.

Sector	Risk	Susceptibility	Issues
Energy	Interrupted supply (e.g. generator or substation) Failure of multiple pieces of equipment	Storms, high winds, bushfire and floods	The implications of a major plant being disabled for an extended period (e.g. one to three months) depends on which plant is affected and at what time of year (e.g. during a heatwave)
Water (includes natural assets e.g. catchments, waterways, etc., and long-lived constructed civil, mechanical and electrical assets such as dams, pipelines, treatment plants, pumping stations, data acquisition systems and desalination plants)[31]	Reduction in supply; changes to customer demand; increased risk of pipe corrosion; capacity of plants and networks exceeded; threat to worker safety, pipe failure and disruption to electricity supplies	Increased sea levels and storm surges, more extreme hot days and intense bushfires, changes in soil conditions, more extreme storms	Water-related infrastructure includes pumps, processing plants, monitoring equipment, all of which rely on power and telecommunication. As such, water networks are vulnerable to climate impacts on other infrastructure
Telecommunications	Loss of communication essential to emergency management[22]	Extreme climate events such as bushfires, intense storm events and flood events causing scouring/ washouts	The most vulnerable part of the fibre network are buried trunk cables. Mobile networks in major cities are microwave linked, with low reliance on cables but at risk from interrupted power supply, although there is generally up to eight hours of back-up generation supply built-in
Railways	Interruption to services, direct damage to assets, passenger discomfort	Heavy rain causing flooding, embankment slippage and slope failures; sea-level rise and storm surge; bushfire, extreme temperatures causing loss of electricity supply	Low-lying assets are highly vulnerable
Roads	Impact on road safety and road serviceability, road disruptions and closures, road fatalities	Inundation and shoreline recession due to sea-level rise, high temperatures, altered rainfall	Nationally, between 26 000 and 33 000 km of roads are potentially at risk from the combined impacts of inundation and shoreline recession due to sea-level rise

Sector	Risk	Susceptibility	Issues
Ports	Impact on service operations and supply chain (both on water and land); safe port navigability, piloting and loading/unloading operations	Sea-level rise, storm surge, increased storminess and more intense rainfall and flooding, electricity service interruption and, to a limited extent, water supply disruption	Hubs for supply chains and transport mean closures have significant potential for economic costs
Airports	Disruption of services	Extreme weather events with higher winds and rainfall; sea-level rise and storm surge	Airports built in reclaimed land on the coast (e.g. Sydney and Brisbane) are subject to the additional impacts of sea-level rise. Brisbane Airport's new parallel runway will have a ground level 1.5 m above the minimum regulatory requirements to avoid the risk of future storm surge, sea-level rise and flooding[25]
Community infrastructure (e.g. hospitals, places of education and worship, libraries and cultural facilities such as art galleries, childcare and preschool facilities, aged-care facilities, police and fire stations, and passive and active open spaces)	Disruption to services, physical degradation of assets; loss of power, water, transport or telecommunications services	Higher temperatures and increased number of heatwave days, flooding, storm surge and sea-level rise (depending on location), bushfire	The diversity of community infrastructure makes it difficult to pinpoint key vulnerabilities; impacts on some community structures necessarily affect some of the more vulnerable members of our society (e.g. residents of aged-care facilities)

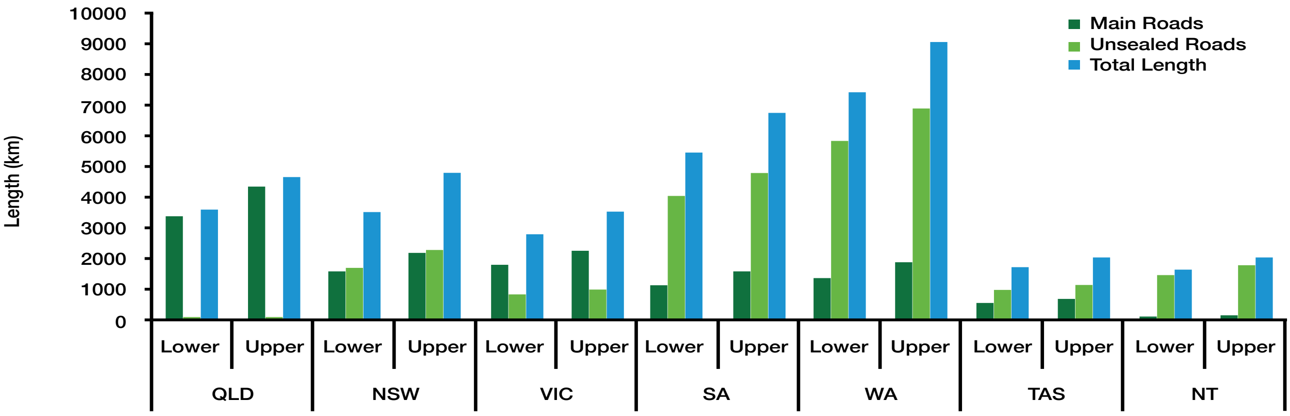

Figure 1: Estimated length of road infrastructure at risk from the combined impact of inundation and shoreline recession for a 1.1 metre sea-level rise. Source: DCCEE[11]. © Commonwealth of Australia 2011.

Figure 2: Heavy rainfall led to flooding of Sydney's rail network in 2012. Source: Sydney Trains.

2. The research base informing adaptation

The legislative and policy environment

Legislative and policy controls generally set the parameters of planning, design and function of infrastructure. While there is a growing awareness of climate risk across all levels of government[12], recent reviews have identified that any responses are piecemeal and that institutional frameworks and structures tend to be largely inflexible and siloed.[17] Poor communication within and between industry sectors can be an obstacle to adaptation.[5,12] Many of the policy domains affected by climate change (e.g. urban water governance, emergency management, planning and development, etc.) are fragmented, and so planning often does not include all the necessary players. In some cases, this can lead to perverse incentives (e.g. around disaster relief policy) or conflicting policy goals.[12]

Current legal and policy arrangements generally apply only to new infrastructure, and exclude existing infrastructure except in certain circumstances (e.g. in-fill developments or post disaster reconstruction).[12] While there is evidence that existing arrangements are adequate in terms of legal prescription, they do not appear to adequately support climate adaptation in practice.[12]

There are few government incentives designed to promote adaptation by the private sector.[16] While there is little precedence at this stage, it is likely that market forces and risk management practices (e.g. legal risk, insurance costs) may have a greater role in driving change in the private sector[16] (see discussion below).

Damage to long-lived infrastructure (e.g. bridges, roads) during extreme events provides an opportunity to consider future needs in rebuilding. However, disaster policy is currently focused on recovery rather than risk reduction by an estimated 50 to 1.[23] This focus on recovery is likely to be counterproductive in terms of reducing risk at both a financial and institutional level.[17] Some new policy provisions (e.g. Natural Disaster Relief and Recovery Arrangements; Betterment Funding) do support rebuilding damaged infrastructure to a better-adapted standard, although local governments may lack the funds to meet part-costs if required.[17]

Building the business case

Incorporating climate adaptation in infrastructure planning and design is likely to require significant upfront investment and a strong business case. While most governments are investing in climate change adaptation, Hussey and colleagues found few of those government bodies could articulate the business case to support their investment[12], although it is likely that future investment may need to be supported by a clear business case.

The long timeframes required for major infrastructure make developing and evaluating a business case difficult. Long-term risk/benefit analyses are required to project decades into the future, with the risk that issues may arise after the completion of the project but during the life of the asset. All of these are challenging to account for upfront. In addition, any social benefits tend to be outside the scope of any private sector investment decisions.[23]

Carmichael and Balatbat identify three options for investing in new infrastructure under climate change: (i) build for today's conditions and abandon in the future because of climate change; (ii) build for today's conditions with the view to being able to modify or upgrade in the future; and (iii) build for future conditions such that infrastructure is overdesigned for the near future but adequate for the longer term.[4] A number of financial analysis methods are available for decision-making in infrastructure that allow for the inclusion of the uncertainties of climate change.[4]

Discount rates are generally used to determine present value for future returns on investment. However, the current framing of discount rates provides no clear direction as to what rates are appropriate for different circumstances, especially over long timeframes.[17]

Degradation in service delivery and performance is likely. The degree of degradation (if any) which is deemed to be acceptable will vary within each infrastructure sector and across communities. For example, differences are likely between cities and remote areas, and in time. The community's (customer) willingness to pay for the costs of climate change adaptation to meet agreed service performance criteria is not yet well understood. Acceptable service performance and willingness to pay should be incorporated in design standards.

Supporting private investment

Private investors are significant providers of finance for long-term infrastructure assets (e.g. industry superannuation funds, property investment trusts, retail and wholesale fund managers, etc.).[3] Climate risk is gaining awareness amongst financial regulators. Australia's prudential regulator, APRA, has recently highlighted the exposure of banks and insurers, for example, to risks around real estate impacted by climate change, or re-pricing (or even 'stranding') of carbon-intensive assets in their loan books. Asset owners and investment managers (e.g. the superannuation sector) are also exposed. Risks may be indirect, for example arising from changes in policy, law, markets, technology and prices as part of the agreed transition to a low-carbon economy.[28] Internationally, the Financial Stability Board's Task Force on Climate-related Financial Disclosures (TCFD) in its final recommendations made it clear that companies should be disclosing the risks and opportunities to their business from climate change, how those risks are identified and what strategies are being used to minimise them.[29]

The Centre for Policy Development and the Future Business Council released a legal opinion in 2016, which advises that company directors that fail to properly disclose foreseeable climate-related risks could be held personally liable for breaching their statutory duty of care and diligence under the Corporations Act.[13]

In the construction and logistics sectors (particularly infrastructure developers) some businesses are endeavouring to gain market advantage by anticipating changing needs for current and new products based on an assessment of projected climate changes.[17]

Several options exist for private investment in adaptation related to infrastructure. However, while financiers recognise the need to adapt to climate change, and the need to finance this, the concept of 'adaptation finance' is not yet in the mainstream.[3] At this stage, the majority of climate change investment is focussed on mitigation projects (with an easier measure of benefit) rather than reducing the impacts on assets where the benefits from investment only become clear over long time periods.[3]

The role of local government

In 2011, spending on infrastructure services equated to 13.3 % of GDP, with the amount of expenditure expected to double to $377 billion by 2031.[14] Australia's local governments are responsible for a significant range and extent of infrastructure assets, the majority of which are long-lived infrastructure including roads, stormwater and freshwater supply assets. Operating expenses (maintenance and depreciation) associated with assets are a much higher proportion of total expenses for local than for state or federal government.[2]

For local councils, maintenance and replacement of hard infrastructure is guided by the principles, models and tools provided in the International Infrastructure Management Manual, developed by the Institute of Public Works Engineering Australia (IPWEA). Balston and colleagues identified that these tools do not allow for the incorporation of climate change impacts nor do they calculate the likely flow-on effects to asset and financial management.[2] In response, they developed a financial asset management model and tool for use by Councils.[2] It provides a comparative analysis of the financial impacts of climate change for different road types. Over the periods modelled the incremental impact of climate change on road infrastructure was generally small and positive, with respect to both useful life and costs.

IPWEA has recently developed an online resource NAMS. Plus (version 3) to assist local governments to sustainably manage their assets. This now includes modelling of climate change impacts for road assets.[15]

Adaptive capacity

The location and configuration of settlements and critical infrastructure can influence the vulnerability and resilience of communities to climatic events[18,27], and so infrastructure plays an important role in building adaptive capacity of communities. For example, Harvison and colleagues identified the importance of adaptive community infrastructure and the built environment for the aged population.[11] Failure of heat sensitive infrastructure (e.g. electricity supply) increases the vulnerability of those who are already very vulnerable to extreme heat conditions, such as elderly people.

Similarly, infrastructure managers and financiers can have more or less adaptive capacity themselves. In the mining industry, for example, an existing culture of risk planning and preparation provides an opportunity to use adaptive management focusing on climate change, to improve adaptation to climate change.[19] Among development firms, those with a greater adaptive capacity tend to be larger, with greater economic resources, and have less reliance on bank funding. They also tend to have a diverse range of development products, and a greater capacity to contract specialist consultants. Commercial developers are more likely to incorporate adaptive measures into developments than residential developers.[27]

Jones and colleagues identified that to build financial capacity for infrastructure investment, funding should:

- be long-term and not constrained by election cycles
- address both soft and hard infrastructure requirements rather than create siloed funding likely to lead to maladaptation
- guarantee drip-feed funding over the long-term enabling bodies that access these funds to invest in long-term strategies using shorter-term investment cycles
- include reimbursement models (e.g. that used by Austrade), where a percentage of expenditure on specific tasks is returned after implementation. This is particularly useful for stimulating early innovation in the private sector.[17]

Many stakeholders identify the potential role for insurance in building adaptive capacity. Insurance can provide pricing signals of increased or increasing risk and thus provide market incentives to increase adaptive measures or avoid high-risk locations or projects.[20]

Evidence of developing adaptation practice

There is growing evidence of adoption and implementation of adaptation practice and planning among infrastructure sectors. For example, the energy sector already manages interrupted supply through load shedding or power sharing. Electricity distributors can also reduce their vulnerability by reducing peak demand.[9]

Some sectors are already implementing adaptation measures in developing, maintaining or upgrading infrastructure. For example, the water sector is actively responding to the risks of climate change. Adaptation strategies that are being investigated include resilient infrastructure design, diversification of water sources (including stormwater harvesting), reduction of demand, better planning and management (Water Sensitive Urban Design or WSUD), incorporation of climate risks into decision-making, improved development planning and planning for the risks of service interruption.[31] The Infrastructure Sustainability Council of Australia (ISCA - isca.org.au) has developed a comprehensive rating system for evaluating sustainability across design, construction and operation of infrastructure. It includes assessment of climate change adaptation in its rating scheme. In terms of operations, many utilities are investing in back-up power generators to mitigate power outages in extreme events.

Climate change adaptation in telecommunications infrastructure companies tends to be framed in terms of energy efficiency and extreme event management. Key adaptation strategies include diversity (e.g. having multiple paths of service delivery) and redundancy (e.g. additional assets such as backup generators which play an important role in managing dependency upon electricity infrastructure).

For railway services, adaptation strategies include improved asset management, maintenance and condition monitoring, extreme weather forecasting, geotechnical monitoring, development of extreme weather response and alternate customer journey plans, measures to improve passenger comfort and information systems, reviews of risk exposure from insurance coverage, and consideration of adaptive capacity in design standards.

3. Evidence-based policy implications

ADAPTATION CHALLENGE 1:

Addressing operational risks at the design phase

Despite an increased consideration of extreme climate events (e.g. floods, cyclones, bushfire) in the design of infrastructure, operational and maintenance impacts can inevitably prove to be the greatest weakness leading to service delivery failure and higher costs for infrastructure managers. To improve resilience and save costs, project procurement and operational practices need to be included as part of the design process and communicated through to construction managers and users.

Anecdotes shared at the practitioner workshop illustrate how maintenance issues can negate adaptation design measures or increase climate risks:

- ·A building in Brisbane was designed to have plant equipment on the second floor to avoid flood risk, however elevators default to the basement level when not in use and therefore into floodwaters.
- Certain pumps within a wider water supply system were individually not deemed 'critical infrastructure' so that the pump room was not air-conditioned. However every day over 30°C the pumps stopped working.

There are numerous operational management functions that can be implemented to reduce climate risk, which are simple and inexpensive but are often overlooked. There are several reasons for this, including a disconnect between the design process, the procurement and construction process and the final users. Reducing risk requires drilling down to operations (e.g. identifying the emergency assembly point in a flood zone) during the design phase and building connections with clients throughout the design and construction phases.

ADAPTATION CHALLENGE 2:

How to maintain and upgrade existing infrastructure

Some infrastructure has a design life greater than 50 years. Where infrastructure exceeds 50 years old, it may not be designed for current or future conditions. For example, drainage systems designed 50-100 years ago are unlikely to have been designed for stormwater generated in today's cities. Asset managers may be faced with:

- increasing maintenance costs
- a need to consider if upgrading the infrastructure is feasible
- early replacement.

Revision and review of the risks to existing infrastructure are likely to need to consider the costs of alternative approaches to improving its resilience. For example, increasing maintenance costs (potentially including downtime of asset function) may be greater than the cost of upgrade. There are limitations to the possibilities of retrofitting or upgrading existing infrastructure. For some, upgrading will not be possible so that early replacement may become the only feasible option.

In considering the retrofit or upgrade of infrastructure there will need to be closer connections between the 'built form' professions, climate change scientists, natural resource managers, insurance providers, and emergency management officials to ensure that the asset is resilient to future changes.

Any infrastructure that is damaged or impacted by climate related pressures should be built back to a higher design standard ("betterment"), thus increasing resilience to future climate impacts.

ADAPTATION CHALLENGE 3:

Managing the transition from past to future

In constructing new infrastructure, asset owners may build to present conditions, but must retain in the design the capacity to upgrade in the future or for future conditions. Including such redundancy in the design is not gold plating, but ensures costs are saved if future upgrades are required.

There can be mismatches between planning and building conditions for new construction and the existing supporting infrastructure. For example, new buildings may be built to withstand higher flood levels, while existing roads servicing the properties are not. Policy-makers will need to consider how they can help to increase the resilience of entire areas in a strategic way, rather than on a piecemeal basis.

ADAPTATION CHALLENGE 4:

Communicating risks

There are many challenges in communicating climate risk, and different approaches may be required for investors, developers and construction companies. For developers and investors, the imposition of measures to address a future risk can appear to simply be an obstacle to their success. From a local authority perspective, the need to address risk is important for safeguarding their communities and avoiding future remediation costs associated with risky development.

A joint approach by sections of government responsible for planning and infrastructure to dealing with developers is likely to improve communication and ensure consistent messaging. Key points include:

- Considered choice of language. Discussions around climate change and provision of information need to be 'de-scienced' and 'de-politicised'
- In communicating climate projections it is important to explain where the information comes from and how projections are derived
- Ensuring that there is an understanding that setting a risk level does not mean that the issue is resolved and need not be thought about again. Residual risk beyond the design level needs to be recognised as a distinct possibility.

ADAPTATION CHALLENGE 5:

Building the business case

Most infrastructure represents a significant financial investment and asset owners seek the best value for money. It is important that climate change risks, including avoided costs of impacts, are included in the business case for an asset or project.

Business cases should include consideration of the trade-offs between benefits and costs for private and public stakeholders. Some values are difficult to quantify, for example, amenity and ecosystem values (e.g. access to a beach). Often those things that can't be monetised can be highly important to the community. Also, how much should a developer or investor be expected to pay before or during construction to prevent potential future public expenditure? So, for example, is it acceptable for a developer not to build to a standard that will prevent flooding in 30 years based on the assumption the government will provide flood mitigation and protection measures to a community to reduce that risk?

Policy incentives may assist in promoting the business case for investing in adaptation measures. For example, adopting principles of sustainability can give a competitive edge to a project. Standards such as those developed by ISCA might be imposed to ensure contractors meet these higher standards. It is important to acknowledge the motivation of different parties in the process of developing infrastructure and development. For example, the contractor has some ability to shape the specifications while the infrastructure builders are more likely to see the business case for improving community resilience, as they will be the ones who interact with the infrastructure in the future. Policy should leverage the motivations of each party in developing appropriate and effective adaptation measures.

A focus solely on the economics of the business case runs the risk of making inappropriate decisions when faced with complex problems. It is important in building a business that decisions are good decisions, not simply ‘cheap’ decisions. There is likely to be infrastructure that is critical for the community in the long-term. It is unlikely that standard economic models will support adaptation measures in these projects yet the long-term social and financial impacts could be significant (e.g. storm water systems have a very long design life and potential to contribute to significant flooding if insufficient to cope with conditions and are incredibly expensive to upgrade). It may be necessary to consider different principles (rather than standard economic models) in assessing these types of critical long-term community infrastructure.

Business cases should include the economic benefits of staged approaches to ensure that developments can be upgraded over time.

ADAPTATION CHALLENGE 6:

Supporting good decision-making

Achieving good decisions that represent a reasonable business case and good value for money while building community resilience may be difficult to achieve but are highly desirable.

Good decision-making is likely to include:

- Consideration of long term operation during the planning phase
- Good communication and sharing of information with and between investors, designer, contractor, owner and regulatory authorities from the earliest stages of planning and development
- Consideration of future conditions rather than relying on historical precedence
- Communicating the benefit-cost of action or inaction
- Consideration of interconnectedness and interdependencies of infrastructure. For example, in constructing a light rail the tracks can be raised but additional stormwater drainage measures must be implemented to avoid adversely affecting water flows into an already stressed council drainage system
- Building redundancy into the development to support upgrading at a later stage.

Likely policy approaches might include:

- Procurement standards proposed at an early stage of planning, driven by the client’s requirements (e.g. materials must withstand extreme climate events)
- Provision of upgraded engineering standards that accommodate industry innovation
- Regulations to meet standards such as those developed by ISCA
- Ensuring design principals of adaptation are not lost through incremental changes made during individual stages of approval process. For example, a case manager that understands the design rationale can more effectively shepherd the project through the approvals process
- Avoiding political decisions that compromise the project design (e.g. completion of project to election timelines meaning suboptimal supporting infrastructure)
- Allowance for different economic modelling principles for long-term critical community infrastructure.

4. Key information and references

Key NCCARF-supported research is marked with an asterisk*

1. ATSE (2008) Assessment of impacts of climate change on Australia's physical infrastructure (Australian Academy of Technological Sciences and Engineering, Parkville, Victoria).
2. Balston J.M. et al. (2013) Quantifying the costs of climate change on local government assets (National Climate Change Adaptation Research Facility, Gold Coast).*
3. Banhalmi-Zakar Z. et al. (2016) Mechanisms to finance climate change adaptation in Australia (National Climate Change Adaptation Research Facility, Gold Coast).*
4. Carmichael D. and Balatbat M. (2010) Uncertainty and infrastructure investment appraisal, ACCARNSI Discussion Paper, https://www.nccarf.edu.au/sites/www.nccarf.edu.au.settlements-infrastructure/files/file/ACCARNSIdiscussion-paper-investment.pdf (accessed 6 December 2017).*
5. Climate Institute (2012) Coming Ready or Not: Managing climate risks to Australia's infrastructure (The Climate Institute, Sydney).
6. DCCEE (2011) Climate change risks to coastal buildings and infrastructure: A supplement to the first pass national assessment (Department of Climate Change and Energy Efficiency, Canberra).
7. Engineering the Future (2011) Infrastructure, engineering and climate change adaptation – ensuring services in an uncertain future (The Royal Academy of Engineering, London).
8. Finkel A. et al. (2017) Independent review into the security of the national electricity market. A blueprint for the future (Commonwealth of Australia, Canberra).
9. Foster J. et al. (2013) Analysis of institutional adaptability to redress electricity infrastructure vulnerability due to climate change (National Climate Change Adaptation Research Facility, Gold Coast).*
10. GHD (2012) Coastal hazard adaptation strategy for Townsville City Council Pilot project. Report for Townsville City Council, https://www.townsville.qld.gov.au/__data/assets/pdf_file/0016/7036/Coastal_Hazard_Adaptation_Strategy.pdf (accessed 6 December 2017).
11. Harvison T. et al. (2013) Ageing, the built environment and adaptation to climate change - ACCARNSI Discussion Paper, https://www.nccarf.edu.au/settlements-infrastructure/content/ageing-built-environment-and-adaptation-climate-change-tracie-harvison-rachelle-newman-and (accessed 6 December 2017).*
12. Hussey K. et al. (2013) Statutory frameworks, institutions and policy processes for climate adaptation: Do Australia's existing statutory frameworks, associated institutions and policy processes support or impede national adaptation planning and practice? (National Climate Change Adaptation Research Facility, Gold Coast).*
13. Hutley N. and Hartford-Davis S. (2016) Climate change and director's duties – Memorandum of Opinion (Centre for Policy Development and Future Business School). http://cpd.org.au/wp-content/uploads/2016/10/Legal-Opinion-on-Climate-Change-and-Directors-Duties.pdf (accessed 20 December 2017).
14. Infrastructure Australia (2015) Australian infrastructure audit. our infrastructure challenges. Executive summary (Australian Government, Sydney).
15. IPWEA (2017) NAMS.PLUS3, http://www.ipwea.org/Go.aspx?NavigationKey=b4c32284-010a-44ee-956a-94ef80475cf2 (accessed 6 December 2017).
16. Johnston G.S. et al. (2013) Climate change adaptation in the boardroom (National Climate Change Adaptation Research Facility, Gold Coast).*
17. Jones R.N. (2013) Valuing adaptation under rapid change (National Climate Change Adaptation Research Facility, Gold Coast).*

18. Macintosh A. et al. (2013) Limp, leap or learn? Developing legal frameworks for climate change adaptation planning in Australia) National Climate Change Adaptation Research Facility, Gold Coast).*

19. Mason L. and Giurco D. (2013) Climate change adaptation for Australian minerals industry professionals (National Climate Change Adaptation Research Facility, Gold Coast).*

20. McAneney J. et al. (2013) Market-based mechanisms for climate change adaptation: Assessing the potential for and limits to insurance and market based mechanisms for encouraging climate change adaptation (National Climate Change Adaptation Research Facility, Gold Coast).*

21. NSW OEH (2014) Towards a resilient Sydney - Urban adaptation research synthesis (NSW Office of Environment and Heritage).

22. NSW Public Works (2011) Analysis of impacts on NSW infrastructure of extreme events under climate change: Telecommunication Sector Workshop: Record of Discussion and Outcomes (NSW Public Works, Sydney).

23. Productivity Commission (2012) Barriers to effective climate change adaptation. Report No. 59, Final Inquiry Report (Australian Productivity Commission, Canberra).

24. QUT (Queensland University of Technology) (2010) Impacts and adaptation response of infrastructure and communities to heatwaves: The southern Australian experience of 2009 (National Climate Change Adaptation Research Facility, Gold Coast).*

25. Rissik D. and Reis N. (2013) Brisbane Airport - New parallel runway project climate change adaptation good practice - Case Study (National Climate Change Adaptation Research Facility, Gold Coast).*

26. Royal C. (2015) (unpublished) Sydney Trains climate change risk assessment and adaptation management plan: An evidence-based approach to climate change risk assessment and management, Sydney Trains.

27. Shearer H. et al. (2013) The capacities of private developers in urban climate change adaptation (National Climate Change Adaptation Research Facility, Gold Coast).*

28. Summerhayes G. (2017) Australia's new horizon: climate change challenges and prudential risk. Speech to the Insurance Council of Australia Annual Forum 2017 Sydney, 17 February 2017, APRA, Canberra.

29. Task Force on Climate-related Financial Disclosures (2017) Final Report: Recommendations of the Task Force on Climate-related Financial Disclosures (June 2017). https://www.fsb-tcfd.org/publications/final-recommendations-report/ (accessed 20 December 2017).

30. Woodroffe C.D. et al. (2012) Approaches to risk assessment on Australian coasts: A model framework for assessing risk and adaptation to climate change on Australian coasts (National Climate Change Adaptation Research Facility, Gold Coast).*

31. WSAA (2012) Occasional Paper 27: Climate Change Adaptation and the Australian Urban Water Industry (Water Services Association of Australia).

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