Resilience NSW

NSW Critical Infrastructure Resilience Strategy Guide

A Focus on Strategy Outcome 1: Improved Infrastructure Resilience

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The NSW Critical Infrastructure Resilience Strategy

The Critical Infrastructure (CI) of NSW is exposed to an increasing number of threats, hazards, shocks and stresses.[1,2,3] Disruptions to critical infrastructure can result in loss of life, negative economic impact and harm to communities, including psychological distress.[4] More frequent natural disasters of greater magnitude[5], and a heightened risk profile in relation to criminal threats including cyber-attack[6],[7] mean NSW's infrastructure and organisations must be more resilient than ever.

The Critical Infrastructure Resilience (CIR) Strategy promotes NSW critical infrastructure that can:

- withstand shock events to continue operating; or
- be returned to service as soon as possible after any disruption; and
- responds to long-term stresses.

A focus on physical infrastructure alone will not achieve this. This strategy has three outcomes:

- Improved **infrastructure resilience**;
- Improved **organisational resilience**; and
- Improved **community resilience**.

Infrastructure systems are a compound of engineered, organisational and user subsystems.[8]. To achieve a higher level of critical infrastructure resilience, all subsystems must be supported. This is represented in the outcomes from the strategy:

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[1] Resilience NSW. 2018. *NSW Critical Infrastructure Resilience Strategy.* https://www.opengov.nsw.gov.au/publications/19460

[2] Resilience NSW. 2017. *NSW State Level Emergency Risk Assessment.* https://www.opengov.nsw.gov.au/publications/19463

[3] 100 Resilient Cities. *What is Urban Resilience?* Available at www.100resilientcities.org/resources/

[4] Australian Business Roundtable for Disaster Resilience & Safer Communities. 2016. *The Economic Cost of the Social Impact of Natural Disasters.* Available at australianbusinessroundtable.com.au/our-papers/social-costs-report

[5] State of New South Wales through Office of Environment and Heritage. 2016. *About Climate Change in NSW.* Available at climatechange.environment.nsw.gov.au/About-climate-change-in-NSW

[6] State of New South Wales through NSW Police Force. *Secure NSW: The Current Security Environment.* Available at www.secure.nsw.gov.au/the-current-security-environment/

[7] Commonwealth of Australia. 2017. *Australian Cyber Security Centre 2017 Threat Report.*

[8] Heinimann, Hans Rudolf. *A Generic Framework for Resilience Assessment*. IRGC (2016). Resource Guide on Resilience. Lausanne: EPFL International Risk Governance Center. v29-07-2016

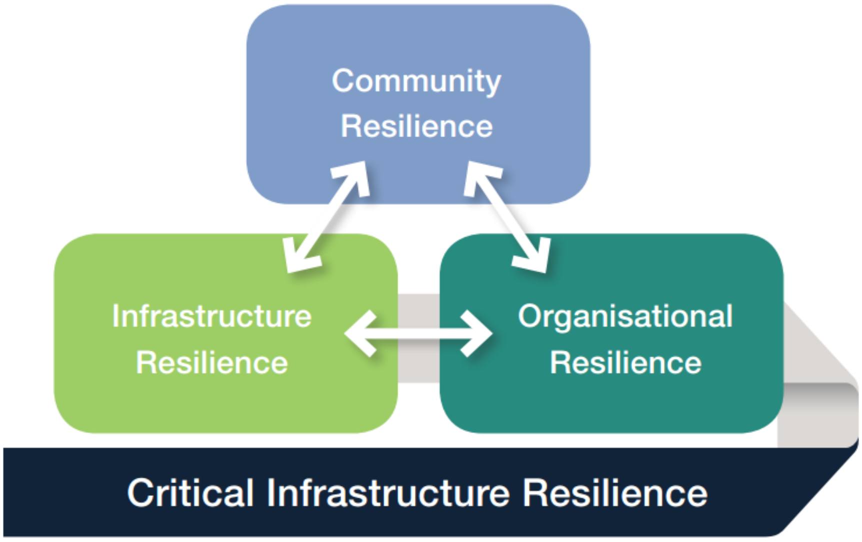

Figure 1: CIR is enhanced through infrastructure, organisational and community resilience[1]

Clicking on each type of resilience will provide more information on how to increase critical infrastructure resilience.

Within each of the outcomes, actions are grouped according to the strategy priorities:

- **Partnering** for shared responsibility around critical infrastructure resilience;
- **Preparing** for all hazards, not just the ones we can foresee; and
- **Providing** continued service from critical infrastructure with minimal disruption.

Together we can build a safer, more secure and more resilient NSW.

Key terminology

Critical infrastructure (CI) is the assets, systems and networks required to maintain the security, health and safety, and social and economic prosperity of NSW. These are underpinned by the organisations and people that support them.

Infrastructure providers include any organisation that provides NSW critical infrastructure, including privately owned organisations, local government, state government, and government-owned corporations.

Critical infrastructure protection (CIP) minimises vulnerability to criminal or malicious threats via physical, procedural, person-based, and electronic defences. CIP is a key part of CIR. At the national level, CIP focuses on mitigation against the specific threat of terrorism. [9]

In NSW, CIP is delivered jointly by the NSW Department of Justice through the Office for Police and the NSW Police Force, by working closely with other NSW agencies and the owners and operators of CI.[10] This Strategy complements existing CIP arrangements by encouraging CI providers in the all-threats and all-hazards approach to protecting CI.

Critical infrastructure resilience (CIR) is the capacity of CI to withstand disruption, operate effectively in crisis, and deal with and adapt to shocks and stresses. It includes the flexibility to adapt to present and future conditions. At the national level, CIR is the term used to describe

[9] Commonwealth of Australia. 2015. *National Guidelines for Protecting Critical Infrastructure from Terrorism.*

[10] State of New South Wales through NSW Police Force. *Secure NSW: Working with NSW Businesses.* Available at www.secure.nsw.gov.au/what-we-do/working-with-nsw-businesses/

an ‘all hazards’ approach to CI activities across the spectrum of prevention, preparedness, response and recovery.

In NSW, while infrastructure providers retain responsibility for CIR, it is delivered as a partnership between infrastructure owners, infrastructure operators, the NSW community, and local, state and federal government.

Within this strategy, CIR outcomes are divided into three categories, or types of resilience:

Infrastructure resilience (IR) is the resilience planned for, designed, and built into assets, networks and systems.

Organisational resilience (OR) is the resilience of the organisations, personnel and processes supporting infrastructure to supply a service.

Community resilience (CR) focuses on the role the community plays in building and maintaining its own resilience while contributing to critical infrastructure resilience.

Strategy Outcome 1: Improved infrastructure resilience

Infrastructure resilience is focused on the resilience planned for, designed, and built into assets, networks and systems.

The goal of improved infrastructure resilience is safer and more reliable physical infrastructure that provides service under all conditions, especially emergencies. At its core, **infrastructure resilience is the ability to reduce the magnitude and/or duration of disruptive events**.[11]

This guide explores the concepts and thinking that sit behind infrastructure resilience. It discusses:

- the elements of infrastructure resilience for assets and networks
- the capacities that improve infrastructure resilience in large-scale systems (interconnected networks of infrastructure)
- the future of infrastructure resilience (disaster risk reduction, climate change, etc.).

Practical ways to increase infrastructure resilience during the asset management lifecycle are supplied in dedicated topic-based guides available from the NSW Critical Infrastructure Resilience Strategy website. These include guides on:

- infrastructure planning;
- infrastructure design, operations and maintenance;
- organisational resilience;
- community resilience;
- criticality assessment; and
- infrastructure interconnectedness.

Industry-specific guidance on ways to increase infrastructure resilience is also available for:

- local government; and
- the energy sector.

NSW infrastructure resilience will not be improved by any single organisation. We must all partner together to provide a safer, more secure and more resilient NSW.

Why improve infrastructure resilience?

Australia will spend over $1 trillion on infrastructure before 2050,[12] with NSW planning to spend over $87bn within the life of this five-year strategy alone. [13]

If integrated early in design, spending just an additional 1%-2% of new infrastructure project budget can provide effective mitigation to natural hazards and climate change.[14] This

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[11] U.S Department of Homeland Security, National Infrastructure Advisory Council. 2009 *Critical Infrastructure Resilience Final Report and Recommendations*.
[12] Australian Business Roundtable for Disaster Resilience & Safer Communities. 2016. Building Resilient Infrastructure. Available at australianbusinessroundtable.com.au/our-papers/resilient-infrastructure-report
[13] State of New South Wales through NSW Treasury. 2018. *NSW Budget 2018-19: Budget Infrastructure Statement 2018-19*
[14] The International Bank for Reconstruction and Development / The World Bank. 2010. *The Cost of Adapting to Climate Change for Infrastructure*.

contributes to savings across all phases of the asset management lifecycle, especially after a disaster, when less time and money is spent on recovery and infrastructure reconstruction.

More important than the cost of the infrastructure is the service and increased amenity that resilient infrastructure will provide. The community benefits of embedding resilience thinking into the planning, design, and operation of services from infrastructure create a double dividend of avoided costs from disasters. Even if a disaster does not occur, the community still experiences co-benefits that arise even in the absence of a disaster.[15]

Almost all infrastructure is a multi-decade investment and most infrastructure will be exposed to many hazards during its life, which can sometimes be in excess of 100 years.[16, 17] On average, reconstruction costs due to natural disasters cost NSW $3.6bn per year with a predicted rise to $10.6bn per year by the year 2050 if we do not build resilience.[12]

While it can be difficult to quantify all cost benefits of integrating resilience into infrastructure, the cost of inaction is higher than the cost of action, considering long-term stresses such as climate change.[18]

Today, New South Wales is planning and building the infrastructure we will be using in 2050, in what will be a very different climate and a very different New South Wales. Embedding resilience thinking in service planning and design will ensure the infrastructure built today will provide reliable services to NSW business and communities for a long time to come. We must strive to ensure that the CI NSW relies on every day suffers minimal disruption and is designed to be restored to operation as soon as possible after any service interruption.

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[15] Australian Business Roundtable for Disaster Resilience & Safer Communities. 2017. *Building resilience to natural disasters in our states and territories*. Available at australianbusinessroundtable.com.au/assets/documents/ABR_building-resilience-in-our-states-and-territories.pdf

[16] Infrastructure Australia. 2016. *Australian Infrastructure Plan: Priorities and Reforms for our Nation's Future*. Available at: infrastructureaustralia.gov.au/policy-publications/publications/files/Australian_Infrastructure_Plan.pdf

[17] National Climate Change Adaptation Research Facility. *Climate proofing Australia's infrastructure*, NCCARF Policy Guidance Brief 7. Available: www.nccarf.edu.au/sites/default/files/attached_files_publications/INFRASTRUCTURE_A4-Webview.pdf

[18] Gallego-Lopez, C.; Essex, J. (with input from DFID) Designing for infrastructure resilience. Evidence on Demand, UK (2016) 22p

Understanding infrastructure resilience

This information highlights the theories and concepts behind infrastructure resilience.

It can help you to create strategies, plans and projects for increasing the infrastructure resilience of your assets, networks and systems. Case studies can highlight ways to improve the elements infrastructure resilience.

Techniques for improving infrastructure resilience should be paired with techniques for improving organisational resilience and community resilience, to create a bigger benefit for the whole NSW community.

This part of the material explores:

- The Elements of infrastructure resilience for assets and networks
- The Capacities that improve infrastructure resilience in large-scale systems (interconnected networks of infrastructure)
- The Future of infrastructure resilience (disaster risk reduction, climate change & sustainability)

The elements: Infrastructure resilience for assets and networks

Infrastructure resilience can be 'hard' or 'engineered' resilience that allows assets to withstand threats or hazards, or it can be the supply of 'soft' systems that allow for better infrastructure planning, such as land use policy and natural hazard risk data.

The four elements of infrastructure resilience within the strategy are illustrated below.[19] They provide different ways to improve infrastructure resilience in single assets or networks.

Improving any element of infrastructure resilience improves overall infrastructure resilience. Considering all elements when planning and designing infrastructure increases the ability to continue to supply service in a greater variety of conditions and be restored to service more rapidly after disruption.

Infrastructure Resilience			
Resistance	Reliability	Redundancy	Enhancing Response and Recovery
Resistance is concerned with direct physical protection. It is CI's ability to withstand shocks to continue operation (e.g. storm surge barriers built to withstand severe storms)	**Reliability** is the capability of infrastructure to maintain operation in a variety of conditions (e.g. electricity networks designed to operate in extreme heat or extreme cold)	**Redundancy** is the adaptability of an asset or network to cope with loss of individual components (e.g. a hospital with two physically separate water supplies)	**Enhancing Response and Recovery** is infrastructure resilience designed to enhance a provider's ability to recover from disruptions. (e.g. modular infrastructure for single part replacement

Figure 1: Elements of infrastructure resilience [1,19]

[19] Adapted from: United Kingdom Cabinet Office. 2011. *Keeping the Community Running: Natural Hazards and Infrastructure.* Available at www.gov.uk/government/publications/keeping-the-country-running-natural-hazards-and-infrastructure

Resistance

Resistance is infrastructure's ability to withstand shocks to continue providing service. It can provide partial or whole mitigation of a threat or hazard. This is often the first element of infrastructure resilience considered, but it should not be used in isolation for improving resilience, as it generally relies on past experience and predictions from historical records.[20]

Reliability

Reliability is the capability of infrastructure to maintain operation in a variety of conditions. Instead of designing assets and systems for existing operating conditions, we should consider the operating and environmental conditions for the whole life of the asset. Long-term stresses such as climate change can impact on reliability and need to be integrated into business-as-usual design.

Reliability is not always an all or nothing experience. Reliable systems often have graceful extensibility engineered into them, which allows them to stretch their boundaries of operation for both negative shocks and positive operating conditions.[21] This may enable continued operation at lower capacities during extreme conditions.

Like resistance, if reliability relies too much on historical data, it may fail to protect against events with impacts beyond its range, such as more severe storms or heatwaves.[15]

Redundancy

Redundancy is the adaptability of an asset or network to cope with loss of individual components. For infrastructure providers with tight capital budgets, this may seem like duplication, but redundancy can be any system or network property that satisfies functional requirements in the event of disruption, degradation or loss of functionality.[22]

As a resilience-building strategy, redundancy can become expensive and may be reserved for systems that have a high level of criticality.

A key aspect of redundancy is implementation time. In electricity or communications networks, inbuilt redundancy can continue to supply service almost instantly, but this may not be the case for other infrastructures such as water or transport.

Enhancing response and recovery

Enhancing Response and Recovery includes any measure designed to enhance the speed of infrastructure service restoration after disruption. This element is not the actual response and recovery from the organisation supporting the infrastructure. It is more about designing assets and networks to be restored more rapidly after disruption. An example of enhancing response and recovery is included in the Case Study - Enhancing Response and Recovery: Wingecarribee Shire Council.

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[20] Guthrie P, Konaris, T. *Infrastructure and Resilience* in Foresight - Reducing Risks of Future Disasters: Priorities for Decision Makers (2012). The Government Office for Science, London.

[21] Woods, David D. *Four concepts for resilience and the implications for the future of resilience engineering*, Reliability Engineering & System Safety, Volume 141, 2015, Pages 5-9, ISSN 0951-8320, Available at doi.org/10.1016/j.ress.2015.03.018.

[22] Bruneau et al, *A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities*. 2004. Paper No. 2575, 13th World Conference on Earthquake Engineering. Vancouver, B.C., Canada

For infrastructure services, response is usually about minimising the impacts of short-term disruptions, while recovery focuses on longer-term disruptions. Definitions and timeframes vary by infrastructure industry, organisation, and the scale of the infrastructure damage. As an example, electricity network recovery is usually measured in days and weeks, whereas road network recovery can often be measured in months or even years.

For large-scale damage to infrastructure networks, especially from natural hazards such as earthquakes and cyclones, recovery is often described as reconstruction. This term only really covers the physical aspect of infrastructure service provision, but response and recovery can also cover other actions (such as temporary service provision by non-network means e.g. portable electricity generators).

Further reading

Gallego-Lopez, C.; Essex, J. (with input from DFID) *Introducing infrastructure resilience*. Evidence on Demand, UK (2016) 10p Available at www.gov.uk/dfid-research-outputs/introducing-infrastructure-resilience

United Kingdom Cabinet Office. 2011. *Keeping the Community Running: Natural Hazards and Infrastructure*. Available at www.gov.uk/government/publications/keeping-the-country-running-natural-hazards-and-infrastructure

Mian, J. Da Silva, J. Kete, N. Pritchard, O. Aldea Borruel, X. Goode, W. *Critical Infrastructure Resilience: Understanding the landscape*. www.resilienceshift.org/publication/critical-infrastructure-resilience-understanding-the-landscape/

Building capacity: Infrastructure resilience for complex systems

While the elements of infrastructure resilience are useful for describing improvements to individual assets or networks, when building resilience in large interconnected infrastructure systems (or systems of systems), it may be useful to consider building capacity throughout the entire system.

Infrastructure resilience theory adapts some terms from ecology and complex systems theory when describing large networks.[17] Considering infrastructure system capacities can also help with uncertain situations and contributes to taking an all-hazards approach to infrastructure resilience.

The effectiveness of large infrastructure systems depends upon their capacity to anticipate, absorb, adapt to, and/or rapidly recover from, potentially disruptive events. [16,23,24,25]

Figure 2: Resilience capacities of infrastructure systems (adapted from Francis & Bekera.[17])

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[23] Hickford, A.J., Blainey, S.P., Hortelano, A.O., & Pant, R. 2017. *A Review of Resilience in Interdependent Transport , Energy and Water Systems*. Agenda Setting Scoping Studies Summary Report.
[24] Francis, Royce & Bekera, Behailu. 2014. *A metric and frameworks for resilience analysis of engineered and infrastructure systems*. Reliability Engineering & System Safety. 121. 90–103.
[25] Béné, C. Godfrey Wood R. Newsham A. Davies, M. 2012. *Resilience: New Utopia or New Tyranny? Reflection about the Potentials and Limits of the Concept of Resilience in Relation to Vulnerability Reduction Programmes.* IDS Working Paper 405.

Absorptive capacity

Absorptive capacity measures the "hardness of the system."[26] Absorptive capacity ensures stability by preventing or limiting the negative impact of shocks on infrastructure.[19]

Like the infrastructure resilience element Resistance, absorptive capacity is usually based on a history of known shocks. Focusing only on the absorptive capacity of a system can leave it exposed to unanticipated shocks.

Adaptive capacity

Adaptive capacity is how capable the system is at adapting or changing itself to deal with undesirable shocks and stresses. The changes are usually in response to the undesirable event.

Adaptive capacity is distinguished from absorptive capacity in that adaptive systems change themselves in response to adverse impacts, especially if absorptive capacity has been exceeded.[17] Redundancy often enhances system adaptive capacity, and adaptive systems are usually highly flexible.

Restorative / transformative capacity

Restorative capacity is how recoverable an infrastructure system is after service disruption.[17] It is a measure of how rapid the systems can return to reliable operation. The actual measures used to determine the success of infrastructure restoration vary by infrastructure service and industry.

When referring to community or ecological resilience, restorative capacity is sometimes called transformative, which indicates that after recovery from a shock, a system can attain a higher state of resilience. [27]

Within infrastructure systems, an example of restorative capacity extending into transformative capacity is the resilience concept of "build back better" where an infrastructure is reconstructed to a higher standard to better deal with future shocks and stresses.

Restorative capacity is about swift return of infrastructure service, the extension of this to transformative capacity is about looking beyond the proximate causes of risk and remedying structural or root causes. [20]

Anticipative / predictive capacity

Anticipative or predictive capacity is the ability of a system to anticipate and reduce the impact of shocks and stresses through preparedness and planning.[28]

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[26] Francis, Royce & Bekera, Behailu. 2013. *Resilience Analysis for Engineered and Infrastructure Systems Under Deep Uncertainty or Emergent Conditions*.

[27] H. Jeans, G. Castillo, S. Thomas (2016) The Future is a Choice, The Oxfam Framework and Guidance for Resilient Development, Oxfam. Available at policy-practice.oxfam.org.uk/publications/the-future-is-a-choice-the-oxfamframework-and-guidance-for-resilient-developme-604990

[28] Bahadur, A. Peters, K. Wilkinson, E. Pichon, F. Gray, K & Tanner, T. 2015. *The 3As: Tracking Resilience Across Braced*. Available at www.braced.org/resources/i/the-3as

Predictive approaches can focus on modelling and simulation, and examine how interconnected infrastructures interact, for example, to assess how disturbances cascade through the systems.[16] Key to this concept is reducing disaster risk.

Within infrastructure systems, predicative capacity is commonly enhanced via emergency planning and overlaying infrastructure systems with hazard maps via Geographical Information Systems (GIS). As sensor technology develops more projects are expected to use sensors to enhance the predictive capacity of their infrastructure systems.

Some models for measuring the resilience of systems include capacities that measure the resilience of the people either supporting or using the system. This strategy identifies the links between the organisation, the community, and the infrastructure (represented in figure 1 in the section on The NSW Critical Infrastructure Resilience Strategy in this document). All should be considered when building the capacities of large infrastructure systems.

Resilience element improvements improves system capacities

These capacities are system goals. They do not necessarily tell us ways to practically improve infrastructure resilience, but they allow us to consider goals of resilient systems when planning, designing and engineering resilient infrastructure systems.

The CIR elements highlighted earlier in this guide are likely to provide good guidance on action to improve infrastructure resilience within single systems or assets. Improvements to elements are likely to also improve system capacities.

Further reading

EU-CIRCLE 2017. *Resilience Framework*. Available at www.eu-circle.eu/wp-content/uploads/2015/07/D4.3.pdf

Hickford, A.J., Blainey, S.P., Hortelano, A.O., & Pant, R. 2017. *A Review of Resilience in Interdependent Transport , Energy and Water Systems*. Agenda Setting Scoping Studies Summary Report. www.resilienceshift.org/wp-content/uploads/2017/10/003_A-Review-of-Resilience-in-Interdependent-Transport-Energy-and-Water-Systemst.pdf

IRGC. 2016. Resource Guide on Resilience. Lausanne: EPFL International Risk Governance Center. v29-07-2016. Available at www.irgc.org/irgc-resource-guide-on-resilience/

Measuring Infrastructure Resilience

Measurement Frameworks

There are many theoretical methods trying to measure resilience in infrastructure systems. Over time, models have come from many different sources, [7,29,30] and efforts to have a single measurement of infrastructure resilience are ongoing.[31] Most models are theoretically sound, but they provide varying results when used to assess infrastructure systems in live environments.[32] This emphasises the difficulty of defining and measuring a concept like resilience. It also highlights the difficulty in trying to apply a single measurement to different types of infrastructure that provide different types of service to communities.

There is currently no single set of metrics that can support all decision-making needs. [33,34] In the future, advances in cheap remote sensing, climate modelling and machine learning are likely to provide the sort of data and computing power that will allow more sophisticated resilience measurements in large infrastructure networks. But the infrastructure of tomorrow is being built today, and the hazards and threats to infrastructure won't wait for measurement techniques.

Why Measure Resilience?

Resilience assessment is useful to pinpoint the ability of a set of infrastructure to reduce disaster.[13] This assists when considering where to invest in mitigation or where to protect a population from a potential hazard.

For many infrastructures, vulnerability can be measured after an outage, e.g. in service not provided (e.g. energy not served), or length and duration of service outages, or damage to equipment.[15] This can assist in prioritising mitigation investment for future efforts.

Rather than measuring resilience across an entire asset base or system of assets, this strategy recommends:

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[29] Bruneau M, Reinhorn A. 2006. *Overview of the Resilience Concept*. U.S. National Conference on Earthquake Engineering 2006. Available www.eng.buffalo.edu/~bruneau/8NCEE-Bruneau%20Reinhorn%20Resilience.pdf

[30] Jovanovic, A. Schmid, N. Klimek, P. *Use of Indicators for Assessing Resilience of Smart Critical Infrastructures*. IRGC (2016). Resource Guide on Resilience. Lausanne: EPFL International Risk Governance Center. v29-07-2016.

[31] Jovanovic, A. & Auerkari, P. 2016. *SmartResilience: The concept and its application on critical energy infrastructure in Finland*. Conference: Baltica X, At Helsinki, Volume: 1

[32] Bakkensen, Fox-Lent, Read, and Linkov. *Validating Resilience and Vulnerability Indices in the Context of Natural Disasters*. IRGC (2016). Resource Guide on Resilience. Lausanne: EPFL International Risk Governance Center. v29-07-2016

[33] Willis, Henry H. *Measuring the Resilience of Infrastructure Systems* IRGC (2016). Resource Guide on Resilience. Lausanne: EPFL International Risk Governance Center. v29-07-2016

[34] Gößling-Reisemann, Stefan. *Resilience – Preparing Energy Systems for the Unexpected* IRGC (2016). Resource Guide on Resilience. Lausanne: EPFL International Risk Governance Center. v29-07-2016

- Understanding the supply priorities around sets of infrastructure (these can be community, organisational or economic) and;
- Understanding the connections between infrastructure networks and systems to improve collaboration across different infrastructure types and understand potential upstream or downstream supply vulnerabilities.

Pursuing these two understandings is more likely to result in practical and tangible increases in infrastructure service availability than applying a measurement to resilience. The CIR Strategy guides available on criticality and interconnectedness highlight ways to better understand priority through infrastructure criticality and the interconnections between different infrastructure.

Economic Value of Resilience

The complexity of measuring resilience can make putting an economic value on resilience difficult. Because we have a lot of data around the costs of hazard impacts with infrastructure, it is currently easier to measure the cost of not having resilient infrastructure.[30,33]

We also have a lot of data around avoided costs from integrating resilience into infrastructure. Especially when resilience is integrated early into infrastructure project planning, marginal costs of 1-2% can provide significant return on resilience investment. [35,36,31,33]

Effective Mitigation Investment materials are available through the NSW Critical Infrastructure Resilience Strategy website.

How to Progress Resilience

Current infrastructure resilience practice is more about developing a strategy than performing a measurement.[37] Practical action for resilience enhancement and improvement of infrastructure service provision are better served by an understanding of infrastructure criticality and the interconnections between different infrastructures. When coupled with good risk management techniques (outlined in the CIR Strategy organisational resilience guide), resilience enhancement practices can be effectively targeted and can also prove their economic, social and environmental value.

Further Reading

Argonne Labs. 2013. *Resilience Measurement Index: An Indicator of Critical Infrastructure Resilience.* publications.anl.gov/anlpubs/2013/07/76797.pdf

Sturgess, P. 2016. DFID. *Measuring Resilience. Evidence on Demand*. www.gov.uk/dfid-research-outputs/measuring-resilience

Wills, Henry H. 2016. *Measuring the Resilience of Infrastructure Systems IRGC Resource Guide on Resilience*. beta.irgc.org/wp-content/uploads/2018/09/Willis-Measuring-the-Resilience-of-Infrastructure-Systems.pdf

[35] Multihazard Mitigation Council 2017 *Natural Hazard Mitigation Saves 2017 Interim Report: An Independent Study*. Principal Investigator Porter, K.; co-Principal Investigators Scawthorn, C.; Dash, N.; Santos, J.; Investigators: Eguchi, M., Ghosh., S., Huyck, C.,Isteita, M., Mickey, K., Rashed, T.;P. Schneider, Director, MMC. National Institute of Building Sciences, Washington.

[36] Hall, P. Carter, C. Bill, E. O'Connor, M. Simpson, M. 2017. *Resilience Return on Investment (RROI)*.

[37] Sansavini, G. *Engineering Resilience in Critical Infrastructures*. IRGC (2016). Resource Guide on Resilience. Lausanne: EPFL International Risk Governance Center. v29-07-2016

Priority: Infrastructure criticality

Infrastructure criticality assessment models provide a good foundation for focusing resilience improvements and common terminology for collaboration on CIR.

By using the existing long-standing system for defining the criticality of infrastructure in relation to counter-terrorism,[23] NSW is extending this use for Critical Infrastructure Protection to the all-hazards approach of Critical Infrastructure Resilience.

The system grades infrastructure on the consequence of failure, rather than the likelihood failure will occur. It also considers the likely assistance required to restore infrastructure service.

The system also recognises that context matters, and what is critical from one perspective may be less critical from another.

State	Organisation	(LG) Local Government
Vital		
State-level impact, alternative unavailable within NSW, long-term impact to NSW	Organisation-wide impact, alternative unavailable within organisation, long-term impact to organisation function	LG-wide impact, alternative unavailable within LG, long-term LG impact
Major		
State or Regional impact, major effort or assistance required to restore, medium-term impact to NSW	Impact across most of the business, major effort or assistance required to restore, medium-term impact to organisation function	Affects multiple functions of local government, major effort or assistance required to restore, medium-term impact to LG services
Significant		
Local or Regional impact, additional assistance required from within NSW, short-term impact to NSW	Impact to one or more sections of the business, other business sections provide assistance, short-term impact to organisation function	Affects one or more significant functions of LG, assistance from other parts of the LG to restore, short term impact to LG
Low		
Local impact, additional assistance may be required from within NSW, minimal impact to NSW	Impact to one part of the business, assistance from other parts of the business may be required, minimal impact to whole of business function	Impact to one function of LG, assistance from other parts of the LG may be required, minimal impact to LG function

Figure 3: Applying contextual criticality to different perspectives.[1]

Complexity: Infrastructure Interconnectedness / Interdependency

The infrastructure that underpins everyday life in NSW is complex. Interdependency mapping highlights the need to promote resilience across the entire supply chain that delivers NSW CI. Interdependency becomes interconnectedness, and therefore a strength, when the NSW community of infrastructure providers work together to promote CIR right across NSW.

A sample interdependency model based on electricity supply illustrates the complexities in delivering essential services:

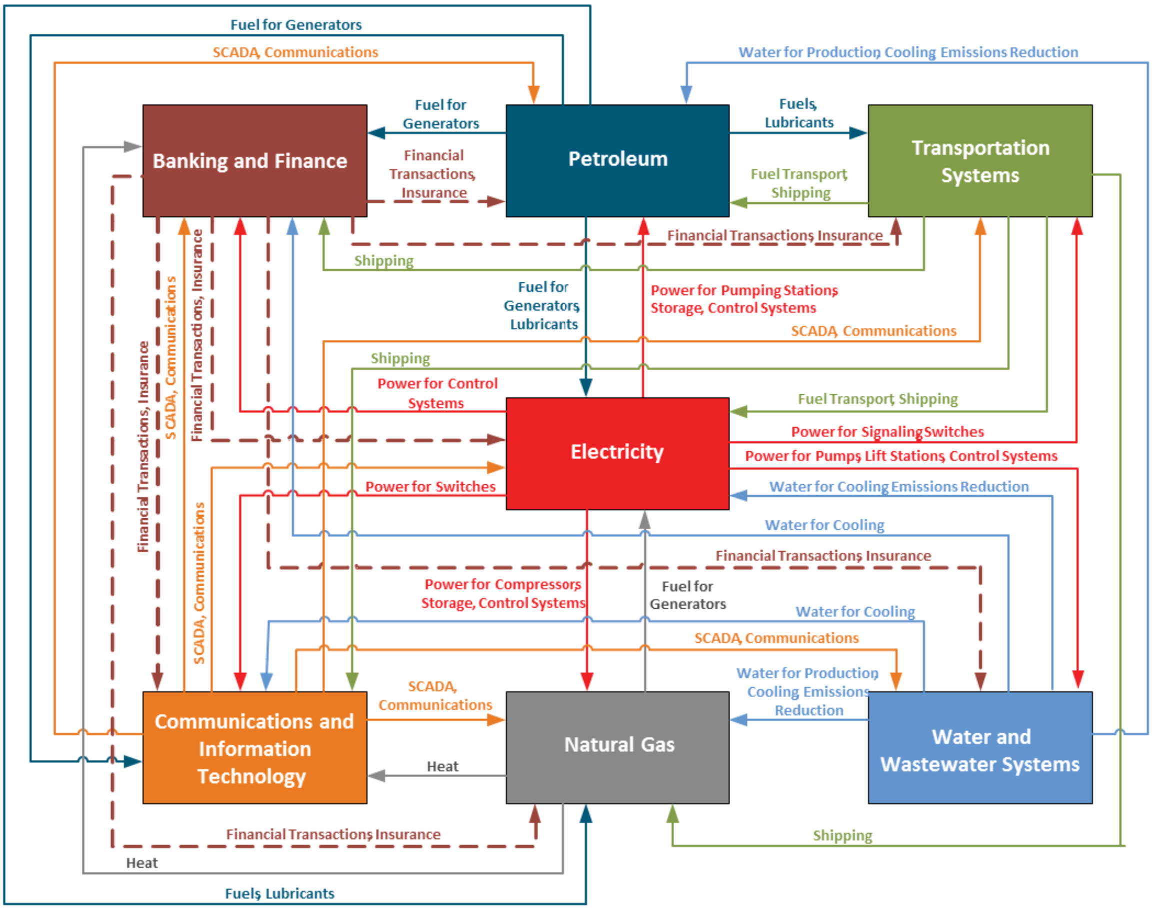

Figure 4: Example of infrastructure system interdependencies. [38]

All CI is dependent to some extent on other infrastructure to operate. The services supplied from energy, water, transport, and telecommunications underpin almost all other critical infrastructure.[23] Interdependencies can look like deficiencies in system design but during normal operation they provide efficiency and enhanced operational capability.

[38] Verner, Duane, Frederic Petit, and Kibaek Kim. 2017. *Incorporating Prioritization in Critical Infrastructure Security and Resilience Programs*. Homeland Security Affairs 13, Article 7 (October 2017) www.hsaj.org/articles/14091

Improving infrastructure resilience

The NSW Critical Infrastructure Resilience Strategy identifies practical ways to improve infrastructure resilience through the planning, design, operations and maintenance phases of the asset management cycle.

These are explored in the CIR Strategy Infrastructure Planning and Infrastructure Design, Operations and Maintenance guides available here.

Table 1: Improving infrastructure resilience[1]

Improving Infrastructure Resilience	
Infrastructure Planning	• Integrated planning and investment • Good data enabling good decision making • Locating infrastructure in less risk-prone locations • Risk avoidance in the planning stage • Hazard mitigation
Infrastructure Design	• Resilience by design • Security by design
Infrastructure Operations and Maintenance	• Maintenance resilience – Maintenance planning – Remote sensors • Operations resilience – Faster service restoration • Reconstruction resilience – Infrastructure betterment in restoration or reconstruction

The future of infrastructure resilience

The resilience journey

Ultimately, the path to resilient infrastructure is a maturity journey.

In the same way that organisations grow their level of maturity around organisational resilience over time and through experience, infrastructure resilience also relies on experience to develop. Once a new level of resilience is achieved, it is time to reset the benchmark to aim for an even better level of resilience.

Infrastructure service providers with frequent exposure to shocks and stresses sometimes develop resilience more rapidly, but all infrastructure providers within NSW must increase their level of resilience. If we don't, we could be passing on the risk of service failure to communities, who may not understand the risk or be capable of dealing with it.[39]

Success occurs when it is business as usual to integrate resilience into the planning, design, operation, and maintenance of all NSW infrastructure.

Cost / benefit of resilience

Although there may be a cost to users of infrastructure to enhance resilience, if the right projects are chosen and the right cost decisions made, the investment in infrastructure resilience will more than pay itself back over the life of the asset.

Reducing disaster risk

Disasters are not natural, they only occur at the intersection of a hazard with a vulnerability. If we increase the resilience of NSW critical infrastructure, we reduce the vulnerability, which in turn reduces the risk of a disaster that overwhelms our ability to respond effectively.

The NSW Critical Infrastructure Resilience Strategy Organisational Resilience Guide provides useful advice on risk management.

Tools, such as the Emergency Risk Management Framework and the State Level Emergency Risk Assessment, are also available from the NSW Government to further assist with reducing emergency and disaster risk. [2,40]

Infrastructure resilience aligns with the all-hazards approach to reducing disaster risk. By building resilience into our infrastructure we can not only cope with known, historical hazards, but also be prepared for unexpected shocks.

Ultimately avoiding a disaster will be beneficial not only for infrastructure providers, but for the communities and businesses that rely on them.

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[39] Crosweller, Mark. 2018 *Resilience and Vulnerability: Two Sides of the Same Coin*. Presentation at A Smart Sustainable Future for All. Melbourne University.
[40] Resilience NSW. 2017. *Emergency Risk Management Framework*. Available at: https://www.opengov.nsw.gov.au/publications/19459

Climate change and extreme weather

Most types of extreme weather events are on the increase and the climate is changing. [41]Warmer temperatures are likely to have adverse effects on the capacity and longevity of many NSW infrastructure networks and systems.[17]

Although uncertainty in climate change projections can't be eliminated, ignoring the large effects of climate change on infrastructure may lead to significant regrets. Focusing on resilience as a way to mitigate the effects of climate change and extreme weather is a cost-effective mechanism to avoid the regrets of building infrastructure without considering future operating conditions.[42]

Tools such as AdaptNSW and the State Level Emergency Risk Assessment[2] are available to infrastructure planners, designers and asset managers to better prepare them for the effects of climate change and more extreme weather on infrastructure.

Sustainability

Infrastructure is a key driver in promoting growth in productivity and community income, as well as health and education outcomes for NSW communities, now and into the future.

The United Nations promotes resilient infrastructure through *Sustainable Development Goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation*.[43] The Australian government promotes the uptake of the UN's *2030 Agenda for Sustainable Development* both domestically and abroad.[44]

Sustainable infrastructure is designed, constructed and operated to optimise long-term economic, social and environmental outcomes and is often closely aligned with resilience to long-term shocks and stresses. Often the measures which create resilience can also create sustainability outcomes.

Tools from the Infrastructure Sustainability Council of Australia are available to ensure that sustainability practices are embedded in each stage of infrastructure project development.[45]

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[41] State of New South Wales through Office of Environment & Heritage. *Climate Change in NSW Fact Sheet*. Available at www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Climate-change/climate-change-fact-sheet-160595.pdf

[42] Cervigni, R. Liden, R.Neumann, J. Strzepek, K. 2015. *Enhancing the Climate Resilience of Africa's Infrastructure: The Power and Water Sectors*. Africa Development Forum;. Washington, DC: World Bank. Available at openknowledge.worldbank.org/handle/10986/21875

[43] United Nations. *Sustainable Development Goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation.* Available at: www.un.org/sustainabledevelopment/infrastructure-industrialization/

[44] Commonwealth of Australia. *2030 Agenda for Sustainable Development.* Available at dfat.gov.au/aid/topics/development-issues/2030-agenda/Pages/default.aspx

[45] Infrastructure Sustainability Council of Australia. 2018. *The Infrastructure Sustainability Rating Scheme*. Available at www.isca.org.au/is_ratings

Further Reading

Australian Business Roundtable for Disaster Resilience and Safer Communities. 2016. *Building Resilient Infrastructure*. Available at australianbusinessroundtable.com.au/our-papers/resilient-infrastructure-report

The Resilience Shift. *Learning from Doing then Sharing our Learning.* Available at: www.resilienceshift.org/publications/

United Nations. *Urgent Need for Disaster Resilient Infrastructure*. Available at: www.unisdr.org/archive/59138

State of NSW. *Understanding and adapting to climate change impacts in New South Wales*. climatechange.environment.nsw.gov.au/

United Nations. *The UN Sustainable Development Goals*. Available at www.un.org/sustainabledevelopment/sustainable-development-goals/

Appendix A: Resilience improvement process

An iterative method for improved infrastructure resilience

Threats and hazards to the continued provision of critical infrastructure service evolve. Some of the threats we face today (cyber, terrorism) were almost unknown in the past, and some familiar hazards have increased in frequency and severity (extreme weather). Technology also plays a part in changing the risk profile around infrastructure.

Infrastructure resilience must also evolve to accommodate this changing landscape. Resilience (in infrastructure, organisations or communities) is a process of continual improvement rather than a destination.

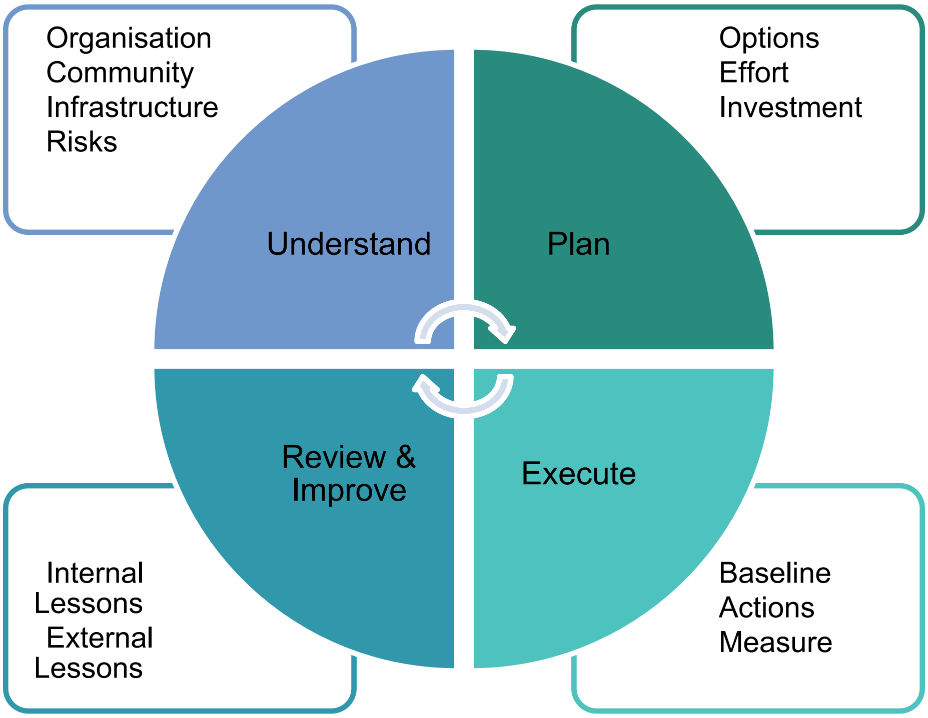


Figure 5: Infrastructure resilience improvement process

Suggestions within the graphic and this table should be tailored to your organisation's own specific requirements and can be integrated into existing processes to improve the resilience of infrastructure assets, networks and systems.

Understand	Your organisation	• goals and mission • appetite for Resilience (CIR Strategy organisational resilience guide)
	Your clients / your community	• expectations (CIR Strategy Community Resilience Guide) • requirements (CIR Strategy Community Resilience Guide, and Infrastructure Planning Guide)
	Your infrastructure	• asset management (CIR Strategy Design, Operate and Maintain Guide) • criticality (CIR Strategy Criticality Guide) • interconnectedness (CIR Strategy Interconnectedness Guide)
	Risks / vulnerability	• natural Hazards (CIR Strategy Organisational Resilience Guide – Risk Management) • human Threats (CIR Strategy Organisational Resilience Guide – Risk Management)
Plan	Investigate resilience options	• brainstorm Improvements (CIR Strategy Design, Operate and Maintain Guide) • prioritise Improvements (CIR Strategy Criticality Guide)
	Effort	• prioritise Further Effort Based on Initial Resilience Dividend (CIR Strategy Criticality Guide)
	Investment	• The Australian Business Roundtable for Disaster Resilience has a cost/benefit analysis methodology. Available at tiny.cc/glguaz
Execute	Baseline	• organisation's metrics for reliability, security, total cost of asset ownership
	Act	• organisation's project management methodology
	Measure	• organisation's metrics for reliability, security, total cost of asset ownership
Review and improve	Lessons	• record lessons (CIR Strategy Organisational Resilience Guide – Lessons management)

Table 2: Sources of information on improving infrastructure resilience

Appendix B: Case studies

Case Study – Resistance: Improving the capability of infrastructure to withstand flooding

City of Wagga Wagga

The City of Wagga Wagga, the largest inland city in NSW, has been subjected to large-scale flood events throughout its history. Risk sources include the Murrumbidgee River and overland flooding from stormwater runoff.

In December 2010, with the Murrumbidgee River already at 7m, 65mm of rain fell within 3 hours overnight. The new predicted peak for the river was 9.7m, and the stormwater runoff overflowed the catchments of Wollundry and Tony Ireland Lagoons, with subsequent flood damage to the adjacent council buildings, including the library, art gallery and basement of the civic centre.

With the assistance of Riverina Water County Council, Wagga Wagga Council installed a temporary pump and pipeline within 10 hours.

Although the temporary solution worked, a better permanent solution was needed.

The council have implemented improvements including:

- Increasing the capacity of the largest catchment lagoon;
- additional floodgates between the catchment lagoons and the river;
- additional bidirectional pumps; and
- additional outflow pipelines.

The new system of pumps and weirs allows the council to reduce lagoon level during flood events, but also ahead of expected flooding in preparation for stormwater runoff.

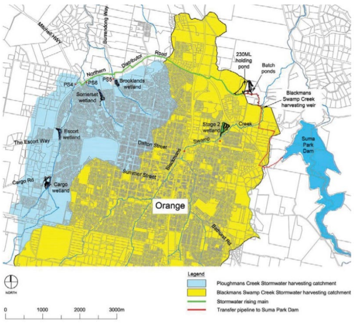
A planned green-space levee between the buildings and the lagoon will create a last line of defence, and will also incorporate seating, artwork and natural features.

Case Study – Reliability: Orange City Council's holistic approach to water supply resilience

ORANGE CITY COUNCIL

The regional city of Orange is 260km west of Sydney and is home to 40,000 people.

During prolonged drought conditions, existing methods of water storage were stretched. Level 5 water restrictions were in place in May 2008 after years of previous water restrictions. During the drought, periodic rainfall missed the rural catchment areas for the city's potable water sources and fell over urban areas. This led the council to look for a solution that would:



- Provide diversity in supply options
- Make the most of all water sources
- Turn potential hazards into opportunities
- Build on existing asset base to strengthen ability to provide infrastructure service.

The Orange stormwater harvesting project supplies approximately 25% Orange's annual unrestricted water needs and consists of:

- Four constructed stormwater wetland systems
- Multiple weirs
- Multiple pump stations
- Extensions of existing infrastructure (pipeline)
- Dual pipe system in new housing since 2005.

The benefits of the scheme include:

- Reduced potable water consumption
- Reduced stormwater pollutants and volumes entering creek - turning waste into a resource
- Increased utilisation of existing assets
- Stormwater flow management including improved drainage corridors and reduced peak flow
- Improved ecosystem function and habitat
- Engaged community
- Improved amenity and passive recreation
- Empowered and engaged staff within council
- Additional experience and increase in efficient delivery of water infrastructure projects
- Improved partnerships and understanding with regulators.

"This was a great project for the Council team as it provided an excellent learning opportunity for our trainee engineers and enabled Council to refine its methods of delivery of key infrastructure projects." Wayne Beatty, Water and Sewer Manager (Strategic), Orange City Council

By assessing the needs of the community and matching the infrastructure to the environmental conditions, the resilience of Orange's water supply infrastructure, and the city's ability to withstand natural hazards has been improved.

A more detailed case study on the Orange Stormwater Harvesting is available online.

Case Study: Redundancy: The Clarence – Coffs water supply project

The $180 million Regional Water Supply Scheme involves linking the Clarence Valley and Coffs Harbour bulk water supplies to meet the demand for water in the region up to and beyond 2046.

This creates a level of redundancy in water supply for the whole region, from both rivers and bulk storage across two NSW local government areas.

Two key elements make up the Regional Water Supply Scheme - A 'non-build' Water Efficiency Program and a $180 million 'build' Project which includes:

- a 30,000ML off-stream storage dam at Shannon Creek, west of Grafton; and
- 87km of underground pipeline distribution system linking the Nymboida River and three water storage areas.

Coupled with the new infrastructure is the regional water efficiency strategic plan, which aims to reduce unnecessary water use to extend the operational life of the scheme. Reduced costs and deferred or avoided future capital investment were also key drivers.

The efficiency plan comprises:

- processes that identify and minimise water losses from leakage and overflows
- water restrictions and pricing policies to discourage inappropriate use of water and optimise the efficiency of supply operations
- incentives to adopt water efficient practices such as re-bates for dual flush toilets, water efficient shower heads and rainwater tanks
- education of communities in environmentally sound water usage; and
- both councils have implemented permanent level 1 water restrictions.

The construction has been planned and designed to both withstand and avoid shocks (floods and other hazards) and long-term stresses (like drought and increasing population). The new dam provides a secure, sustainable and resilient water supply for both Clarence Valley and Coffs Harbour local government areas, which has significant benefits for other interdependent critical infrastructure that relies on water, such as hospitals, food and grocery, and wastewater.

The dam foundations were constructed to allow further construction up to 75,000ML if required in the future, but by managing demand the cost of increasing the size of the dam wall should be deferred for many years.

The ‘off stream’ dam design reduces the likelihood of natural hazards such as large floods, but also minimises environmental impacts as water is only allowed to be taken when flow in the Nymboida River is either not too high or not too low. The run of dry weather in mid-2018 had minimal impact on the availability of water in the dam. This project has won a number of awards for its benefits to the community, the environment and engineering excellence.

Appendix C: Abbreviations and glossary

Abbreviation	Meaning
All-hazards approach	An approach to managing the uncertain nature of emergency risk by building resilience to all or multiple hazards
CI	Critical infrastructure
CIP	Critical infrastructure protection (specifically, against terrorism)
CIR	Critical infrastructure resilience (against all hazards)
Dependency	When a CI relies on another CI, good or service for continued service provision
Disaster	When a hazard or threat intersects with a vulnerability, overwhelming the ability of local resources or business as usual to cope
EMDRR	NSW Emergency Management and Disaster Resilience Review
Hazard	A threat, usually natural, that unintentionally disrupts CI service provision
Infrastructure provider	An organisation responsible for providing an infrastructure service at a state, regional or local level, whether publicly or privately owned
Interdependency	When multiple CIs rely on each other for continued service provision
Mitigation	Measures taken in advance to reduce the likelihood or consequence of a hazard or threat
Sector	An industry or service group identified within the NSW CIR Strategy
SEMC	State Emergency Management Committee
SCADA	Supervisory control and data acquisition systems are used for remote monitoring and control to deliver critical services such as electricity, gas, water, waste and transportation
Threat	A hazard, usually man-made, that deliberately disrupts CI service provision
TISN	Trusted Information Sharing Network is co-ordinated by the Department of Home Affairs
Vulnerability	The conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards. (Source: NDRRF Glossary)

Case Study - Enhancing Response and Recovery: Wingecarribee Shire Council

Wingecarribee Shire Council (WSC) is in the design and implementation phase of a project to install fixed and mobile generation to key water assets in the council network water and sewer networks.

An initial interdependency assessment used knowledge from experienced council engineers and water operations staff to identify key sites within council's water network required to continue service in the event of upstream electricity outages.

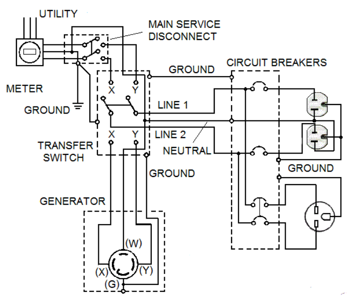
A criticality assessment followed to identify sites vital to the provision of the service that required permanently installed (fixed) generators, and less critical sites that could utilise temporary (mobile) generation. Sites identified for fixed generation include the Wingecarribee Water Treatment Plant and key pump stations.

Figure 1: Wingecarribee Water Treatment Plant and electrical substation with adjacent site for fixed generator

Mobile generation was assessed as suitable for other pump stations and booster sites.

Benefits of the mobile generation include:

- Common equipment between water and sewer sites
- Standard trailers make it easy to deploy and relocate during emergency outages
- Available for small outages, planned outages and maintenance activities



A good understanding of WSC's infrastructure network, coupled with a good understanding of upstream dependencies, has allowed WSC to design a practical and cost-effective project to improve the resilience of water supply for the businesses and communities of Wingecarribee shire and help them respond to, and recover from, unexpected interruptions.

Appendix A Abbreviations and Glossary

Abbreviation	Meaning
All Hazards	An approach to manage the uncertain nature of emergency risk by building resilience to all or multiple hazards
CI	Critical Infrastructure
CIP	Critical Infrastructure Protection (protection against terrorism specifically)
CIR	Critical Infrastructure Resilience (protection against all hazards)
Dependency	When a critical infrastructure relies on another critical infrastructure, good or service for continued service provision
Disaster	When a hazard or threat intersects with a vulnerability, and the ability of local resources or business as usual to cope is overwhelmed
EMDRR	NSW Emergency Management and Disaster Resilience Review
Hazard	A threat, usually natural, that unintentionally disrupts critical infrastructure service provision
Infrastructure Provider	An organisation responsible for providing an infrastructure service at a state, regional or local level, whether publicly or privately owned
Interdependency	When multiple critical infrastructures rely on each other for continued service provision
Mitigation	Measures taken in advance to reduce the likelihood or consequence of a hazard or threat.
Resilience (Hard)	Hard resilience is generally focussed on assets, networks or systems. Examples include levees and reinforced structures.
Resilience (Soft)	Soft resilience is generally focussed on organisations, people and behaviour. Examples include policy and process, emergency and business continuity planning, and community engagement.
Sector	An industry or service group identified within the NSW CIR strategy
SEMC	State Emergency Management Committee
SCADA	Supervisory Control and Data Acquisition (SCADA) systems are used for remote monitoring and control in the delivery of critical services such as electricity, gas, water, waste and transportation.
SLERA	NSW State Level Emergency Risk Assessment
Threat	A hazard, usually man-made, that deliberately disrupts critical infrastructure service provision
TISN	Trusted Information Sharing Network (information sharing network co-ordinated by Commonwealth Home Affairs Department)
Vulnerability	The mechanism by which critical infrastructure can be affected by threats and hazards

Appendix B References