Critcal Infrastructure Resilience Strategy: Criticality Assessment Guide

Resilience NSW
GPO Box 5434
SYDNEY NSW 2001
(02) 9212 9200

Author: Chris Quin (Resilient Projects).

Acknowledgements: The contributions made by all the stakeholders involved in the planning, workshops, and development of the NSW Critical Infrastructure Resilience Strategy 2018 are acknowledged.

Table of Contents

S

Criticality: Why does it matter?

This companion information for the NSW Critical Infrastructure Resilience (CIR) Strategy explores the concept of criticality for prioritisation and explores ways to assess and apply criticality concepts to practically improve infrastructure resilience.

Criticality and infrastructure resilience

Infrastructure resilience revolves around continued provision of infrastructure service, even in the worst of conditions. However, it is not feasible to build all infrastructure to be able to withstand every possible threat or hazard it could face during its lifetime.

Criticality is a tool used to help determine what infrastructure is most critical to customers, the community, infrastructure providers, and other interconnecting infrastructure and services.

Criticality aids **understanding**. By understanding the criticality of infrastructure assets, networks and systems, and then collaborating with other infrastructure providers, group understanding is further increased, and problems avoided with upstream and downstream infrastructure service supply or interdependencies. (More information around the interconnectedness of infrastructure can be found in the CIR Strategy Interconnectedness Guide.)

Primarily, criticality is a tool to **prioritise**, so that attention can be focused on where to get the most reward for invested efforts to improve infrastructure resilience.

Additionally, the CIR Strategy seeks to establish **shared terminology** around criticality to promote **shared understanding and interoperability** before, during and after emergency events.

In summary, what is proposed by this guidance material is:

- A Shared Terminology around Criticality;
- Increased understanding of the infrastructure service your organisation provides;
- Increased understanding of the way infrastructure interconnects with other infrastructure services;
- Decreased infrastructure service interruptions; and
- Increased ability to provide infrastructure service during abnormal operating conditions

Knowledge and complexity

Infrastructure networks are complex and complicated systems.

With an infrastructure network of just 1,000 connected assets, almost one million failure scenarios are associated with two points of failure and over one billion with a three point failure scenario.[1] This make it difficult (if not impossible) to account for every possible type of failure in an infrastructure network. Criticality can assist efforts to understand building the resilience

[1] Verner, Duane, Frederic Petit, and Kibaek Kim. "Incorporating Prioritization in Critical Infrastructure Security and Resilience Programs." Homeland Security Affairs 13, Article 7 (October 2017).

of infrastructure networks, by providing focus on the highest-consequence components, and prioritising efforts based on this understanding.

Sometimes due to organisational structure or history, the knowledge of criticality resides with one person or a small number of staff members with a lot of experience. Documenting criticality provides resilience in case these staff members are unavailable during planning or emergency response activities.

Prioritisation aids resilience

Improving the resilience of an entire infrastructure network or suite of assets with one big project is unlikely to be cost and time efficient. Full protection from all threats and hazards is usually not financially viable for organisations or society[2], and may not even be feasible.[3]

Incremental improvement is the key to improving infrastructure resilience, and determining criticality allows prioritisation of those increments. This ensures that the most important aspects of infrastructure service are made more resilient sooner, preparing NSW for future shocks and stresses. This reduces the potential number of failure scenarios, and also the magnitude of those service failures.

---

[2] Apostolakis, George & Lemon, Douglas. 2005. *A screening methodology for the identification and ranking of infrastructure vulnerabilities due to terrorism* Risk analysis: an official publication of the Society for Risk Analysis. Vol 25 2, 361-76

[3] Fekete, Alexander. *Common Criteria for the Assessment of Critical Infrastructures*. Int. J. Disaster Risk Sci. 2011, 2 (1): 15–24

Benefits of assessing criticality

The process of assessing the criticality of an organisation's assets (or formalising existing assessments) reveals a lot about the organisation and its ability to fulfil its mission, especially during times of disruption.

Infrastructure criticality assessment benefits infrastructure providers in the following ways:

- Organisational Resilience & Executive Decision Making
    - Input into how organisation uses inputs to achieve outcomes
    - Reputational enhancement and protection
- Asset Management
    - Prioritise Investment (within a company, an asset portfolio or even an individual project)
    - Better asset planning– understanding criticality (and resilience) will allow better choice of competing projects at planning stage, and better siting of new infrastructure projects.
    - Better asset design – understanding criticality (and resilience) allows integration of resilience and security enhancements to improve operations.
- Operations Management
    - Reduced number of service disruptions
    - Reduced length of service disruptions
    - More efficient allocation of operating budget
    - More efficient allocation of operational resources during both normal business and emergencies
    - Better security of sensitive or critical assets due to focus in design and planning
- Risk Management
    - Better understanding of the likely risks that infrastructure will be exposed to
    - Better understanding of the consequences and mitigations should a risk be realised
    - Better understanding of supply chain risks from other infrastructure services
- Emergency Management
    - Prioritise Restoration (to most effectively and efficiently recover from disruption)
    - Better targeting of training exercises and planning activities to provide better return on investment

Infrastructure criticality assessment also benefits the community and customers who rely on the infrastructure service, as well as interconnected infrastructures.

Further reading

Verner, Duane, Frederic Petit, and Kibaek Kim. "Incorporating Prioritization in Critical Infrastructure Security and Resilience Programs." Homeland Security Affairs 13, Article 7 (October 2017).

Criticality and the CIR Strategy

The CIR Strategy criticality assessment is based on the long-standing Australian National Guidelines for the Protection of Critical Infrastructure from Terrorism. This system has been used for some time from a State or National perspective to establish reporting requirements around infrastructure that could be targeted by a terrorist threat.

The CIR Strategy approach takes a threat-specific method and extends it to the all-hazards approach of CIR. Because the responsibility for infrastructure resilience within NSW occurs at many levels, the system has been adapted for context. This is known as Contextual Criticality.

Contextual criticality

Definitions of infrastructure criticality rely on perspective and purpose. What is vital for a region, may not be vital for a town. What is significant for a CI provider's own organisation, may not be as significant for the State. What is critical during one part of the year, may be less critical at other times. This recognises the size and diversity of NSW, the different expectations the community has on CI providers, and that different jurisdictions and organisations have different resources available to them in an emergency.

Within NSW, organisations are encouraged to adopt the terminology used in this model but scale the terms to assess criticality from their perspective (e.g. in business continuity planning). Simple examples are highlighted below:

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 1: Contextual Criticality Examples

While the examples in Figure 1 grade criticality based on the consequence of failure and the assistance required to restore infrastructure service, some other factors that need consideration are explored in How To Assess Criticality.

Criticality terminology

The terminology of Vital, Major, Significant and Low, as outlined in Figure 1, can be used at all phases of the emergency management cycle (Prevention, Preparedness, Response and Recovery) to assist multi agency planning, exercising and response.

The terminology can also be used in asset and organisational management to assist in the prioritisation of effort and resources to achieving increased critical infrastructure resilience, but of course can be contextualised, especially where more detail is required.

Further reading

Resilience NSW. 2018. *Critical Infrastructure Resilience Strategy.*

How to assess criticality

There are many ways to assess criticality. Ultimately the method used to assess criticality comes down to the purpose of the prioritisation, the type of infrastructure, and the organisation doing the assessment.

It is important to understand the criticality of infrastructure prior to an emergency – if an emergency or significant outage is the event that reveals the criticality of infrastructure, this can have disastrous results for the community, the infrastructure organisation, and considerably increase service restoration times.

Infrastructure criticality assessment has risk management as a foundation. Whether the purpose of prioritising infrastructure is to assess risk, prioritise investment, or allocate resources to restore services, all criticality assessment is a type of risk assessment and management.

Experienced risk managers may see criticality assessment as only half of a traditional risk assessment and this is somewhat true. But it’s important to emphasise consequence over likelihood when assessing criticality of infrastructure. This makes the assessment useful against all hazards and risks rather than limiting it to, a specific risk. Of course, criticality assessments can feed into all other types of risk assessment.

The foundations of criticality assessment: asset management and risk management

Asset management

Strong asset management is vital to criticality assessment, as without a knowledge of the assets that form the infrastructure service, pinpointing vital components can be difficult, if not impossible.

Good asset data allows better criticality assessment that can consider more factors, better prioritisation of resources, and better outcomes in abnormal operating environments. Good asset data requires a good information technology system for recording the data, including criticality assessments. This allows reporting on criticality for input into mitigation and response to hazards and threats.

Sometimes, especially in smaller infrastructure networks, asset data and criticality information is often stored in someone’s head. This can be problematic when that person is on unexpected leave during an emergency or when a significant decision needs to be made. Storing criticality information in your asset management system can help mitigate single points of failure where a lot of information is stored in a single place (e.g. in a single person’s or small number of people’s heads).

Further asset management for critical infrastructure resilience information is available through the CIR Strategy Design, Build and Operate Guide.

Risk management

Risk management for an asset owner provides insight to prioritise the activities and initiatives of the organisation and the allocation of its finite resources. These concepts are explored in more detail in the CIR Strategy Organisational Resilience Guide.

Although criticality assessment is grounded in risk assessment, it usually focuses on the consequence of an infrastructure failure and either doesn't consider likelihood of failure or considers it to a lesser extent than in standard risk management. This is because criticality assessments are used for a wider range of purposes than risk assessment, which usually requires knowledge of a specific threat or hazard.

A criticality assessment is designed to be much more general than a risk assessment. Focusing on a specific threat or hazard can reduce the effectiveness of criticality assessment and leave infrastructure exposed to other threats or hazards. It can also ignore the decentralised nature of some infrastructure networks (e.g. a failure in one location can impact services hundreds of kilometres away) and has the potential to ignore interdependencies with other types of infrastructure.[4]

For these reasons, it is useful to reduce focus on likelihood of failure, at least for first pass or high level criticality assessments. It can always be added at a later stage when considering specific threats or hazards, or when considering where to invest to strengthen an infrastructure network against loss of service.

Like many of the concepts and tools within infrastructure resilience, criticality assessment is a maturity journey, and once criticality is well understood within your organisation, criticality model sophistication can be increased to consider many different elements.

Criticality assessment terminology

The CIR Strategy defines four broad levels of criticality within NSW infrastructure: **Vital, Major, Significant** and **Low**. As outlined in the CIR Strategy, these should be applied from your organisation's perspective to be most effective.

Vital, Major, Significant and Low will mean different things to different organisations but agreeing to use these terms has many benefits. It will assist in joint planning of infrastructure (e.g. where a hazard affects a geographic area, multiple infrastructure owners may contribute to a shared infrastructure protection measure), but also in emergency response. If an infrastructure provider needs help from the emergency services to ensure a Vital asset is protected during a bush fire (e.g. only operating HV electricity line into a regional centre), this can highlight the importance to different agencies and help them prioritise resources as well.

Users of the strategy should not feel limited by the four terms. If an organisation needs 12 levels of criticality for prioritisation of infrastructure resilience investment, they should use 12 levels, but for interoperability with other providers, those twelve levels can still be grouped into the CIR Strategy criticality labels. Examples provided within this guide show how this might work for an infrastructure provider with a large state-wide network of assets.

Determining what is critical

One of the problems in assessing criticality is that almost all assets of an infrastructure service can become critical if the impact to the network or service is large enough. This is especially true for non-linear or meshed networks such as telecommunications infrastructure.[5] Although this can make it difficult to precisely assign criticality to specific assets, this should not stop infrastructure providers from assessing and recording high-level criticality information. Often

[4] Fekete, Alexander. *Common Criteria for the Assessment of Critical Infrastructures*. Int. J. Disaster Risk Sci. 2011, 2 (1): 15–24

[5] Fekete, Alexander. 2011. *Common Criteria for the Assessment of Critical Infrastructures*. Int. J. Disaster Risk Sci. 2011, 2 (1): 15–24

people working closely with these types of infrastructures (e.g. in control rooms) know this information from experience and recording their understanding can be a good first pass at criticality assessment.

Criticality assessment techniques vary right around the world[6], and by infrastructure type[6]. For example, in electricity supply amount of unserved energy, or number of customer minutes without supply might be primary factors in assessing criticality, whereas in transport networks, amount of additional time added to travel routes, or economic impact to industry might be primary factors in assessing criticality. In wastewater criticality could be affected by environmental impact. In infrastructures such as hospitals or health care, the number of avoidable deaths or negative outcomes for patients might be a more critical factor. When very large outages occur across large infrastructure systems, time to repair often becomes a key aspect of prioritising service restoration, and this can be factored into criticality assessments.

These examples show that criticality assessment should be tied closely to the mission or purpose of the organisation supplying the infrastructure service. This will improve its utility and meaningfulness to members of the organisation, including boards, executives and those responsible for mitigation investment decisions.

Factors to consider in developing criticality assessment tools

In the same way that no one type of risk assessment fits every risk, no one type of criticality assessment will suit every prioritisation purpose. Each assessment will need to consider the type of infrastructure and the interconnections to other supporting infrastructure. All criticality assessments however should consider the following three items as a minimum:[7]

- Internal Consequence of Loss (the effect to the infrastructure asset, network or system itself)
- External Consequence of Loss (the effect to customers or other infrastructures of reduced or degraded infrastructure service levels)
- Effort or Resources Required to Improve Resilience or Restore Infrastructure Service

In addition to these main ways to assess infrastructure criticality, factors that may also play a key role depending on the purpose of the assessment on can include:

- Velocity of Loss (Systems that fail or degrade quickly (e.g. an electricity transmission line failing to earth) need a rapid response to minimise damage and prevent cascading faults to a network or interconnected infrastructure.)
- Likelihood of Loss (generally only considered when assessing specific threats or hazards, or determining methods to mitigate the risk of service loss or degradation).

All these considerations can be summed up in a simple question: “What happens if it fails?”

Depending upon organisational purpose, the consequence of infrastructure failure could be measured in lives lost, injuries sustained, property damage, minutes that customers are without service, economic and/or reputational loss. The desire to avoid service interruptions is key to successful criticality assessment.

[6] Katina, P.F. and Hester, P.T. 2012. *Systemic Determination of Infrastructure Criticality*, Int. J. Critical Infrastructures, Vol. 9, No. 3, pp. 211-225

[7] Adapted from: Fekete, Alexander. *Common Criteria for the Assessment of Critical Infrastructures*. Int. J. Disaster Risk Sci. 2011, 2 (1): 15–24

Metrics for criticality assessment: Consequence of loss

While metrics will vary between types of infrastructure some examples of the types of measurements that can assist criticality assessment are provided in the table below.

Table 1: Measurements and Metrics to Assist Criticality Assessment

Item	Measurement / Metric	Examples
Consequence	• Percentage • Whole Number • Economic	% or numbers of customers without infrastructure service supply
		# or % of geographic regions or sectors without supply
		% of lost or remaining service (e.g. network that can only supply a percentage of normal capacity, or amount of total network still operational
		Amount of unserved product (e.g. estimate of unserved energy from electricity networks, or volume of water not supplied)
		Cost of service not being available ($/min or $/hr)
		Personal injury or property damage
Velocity / Time	• Outage Length • Remaining Service (time to loss of supply or degradation of service) • Restoration Effort	# of minutes of service interruption
		Customer minutes (minutes of interruption x number of customers)
		# of minutes to restore service / repair asset
		# of minutes an asset can continue to function without upstream supply (e.g. electricity generator fuel stocks on telecommunications infrastructure)
		# of minutes to switch to an alternate supply (e.g. reroute trains to a different track)
Quality	• Varies by Industry & Infrastructure, but is generally based on a measurable threshold	For example, it may be possible to deliver water to customers, but it may need to be boiled before use

Of course, the measures in the table are quite straightforward and additional metrics around likelihood, vulnerability and velocity can be integrated for more complex situations.

More metrics: Likelihood, vulnerability, velocity and politics

Additional measures such as spatial location or probability of a specific threat can be used in a criticality model, but caution needs to be used when making an assessment too specific, unless resources will be assigned, or mitigation activity undertaken due to a very specific hazard or threat (such as the threat of terrorist activity).

Likelihood, vulnerability and velocity (and other metrics specific to the organisation or its assets) can be factored into criticality assessments in more general ways than in risk assessment and these are outlined below.

Likelihood

Adding likelihood to criticality assessment can be very general. General considerations can include asset age and condition, asset over or under utilisation, and likely asset maintenance budget. Note that this type of likelihood doesn't necessarily specify a threat or a hazard, so is more closely aligned to criticality assessment than a standard risk assessment.

Specific hazards can be factored in, if they suit the organisation's purpose, especially when those hazards have a high likelihood of impact during the life of the asset. As an example, exposure to storm surge or saltwater inundation for assets in low-lying coastal areas may be appropriate to be integrated into a criticality assessment, or even more rapid deterioration in asset condition (e.g. corrosion due to proximity to the coast). It is recommended that specific threats be considered in more detailed criticality assessments after initial passes have been made to determine criticality at a high level over an entire asset base.

Vulnerability

Vulnerability is often better suited to a standard risk assessment than criticality due to the need for a specific threat to heighten the ability to understand how vulnerable an infrastructure asset is.

When vulnerability is considered in a broader sense, it can be very useful to integrate it into criticality assessments and can complement assessments of likelihood of failure.

Vulnerability assessment is particularly useful for Critical Infrastructure Protections against malicious threats. Whether the threat comes from terrorism, sabotage, or cyber-attack, vulnerability assessment can aid in understanding the criticality of infrastructure services and help in prioritising allocation of resources to reduce vulnerabilities and increase resilience.

For an example of how vulnerability can be integrated into assessments from the ground up, see the case study on the New Zealand Lifelines Vulnerability Assessment.

Time and velocity

In addition to a metric to measure customer time without service or to prioritise resources based on effort to restore infrastructure service, time and/or velocity can help to build a more sophisticated picture of criticality.

For example, time of day or year when an outage occurs can create greater consequence of service loss. Electricity outages to traffic signals cause greater consequence during peak hour, unserved electricity during extreme hot or cold weather can have greater consequences than during moderate temperatures. This may need to be considered in a criticality assessment.

Velocity can be a key factor in assessing criticality, as systems or networks that cascade their faults rapidly (e.g. in fractions of a second as in electricity, communications or information technology infrastructure), may be assessed at a higher criticality due to the potential magnitude of a failure, than systems where time for human intervention can reduce the disruption.

Combined assessment theories and models

Many universities and research organisations around the world have developed sophisticated formulas to assist with criticality assessment, and in a mature criticality model, or with good asset data and systems, these can be useful for high-level criticality assessments.

Caution should be used to ensure that these are fit for purpose however, as the underlying assumptions in the models can give varying results in different locations and types of infrastructure networks.

Existing mathematical theories are often used when developing these more complex assessments such as Multi Attribute Utility Theory[8], Bayesian Network Modelling and Multi-path Link State Analysis[9], Fuzzy Logic[10], and even Supervised Learning (from Artificial Intelligence theory)[11]. Combinations of existing theories are frequently used to create greater precision.

Organisations that do not have access to mathematical experts or research partners shouldn't be discouraged from developing a criticality assessment themselves however – an enhanced understanding of infrastructure with a simple system is better than no understanding, or the information being centralised in a single person or small group of persons, and high-end assessments of criticality may take years to develop, whereas knowledge based on experience may be available immediately.

Any method for assessing criticality should be "ground-truthed" by experienced personnel in operating or repairing the infrastructure service to ensure it meets understandings from real-world experience.

Political and reputational factors

Sometimes a criticality assessment is directly affected by politics – the impact to reputations (organisational or personal) based on a significant infrastructure service outage. This can be difficult to integrate into a mathematical model but should be considered as the maturity of an organisation's understanding and use of criticality assessment increases. This is often very important with highly visible infrastructure that may be the target for malicious threats.

---

[8] Koonce, Apostolakis & Cook. 2006. *Bulk Power Grid Risk Analysis: Ranking Infrastructure Elements According to their Risk Significance*. Massachusetts Institute of Technology Engineering Systems Division Working Paper Series.

[9] Tien, I. 2018. *Mapping Infrastructure Interdependencies: Why It Matters and What It Can be Used For*. Critical Infrastructure Resilience Institute. Webinar available at ciri.illinois.edu/content/mapping-infrastructure-interdependencies-why-it-matters-and-what-it-can-be-used

[10] Akgun, Ilker & Kandakoglu, Ahmet & Fahri Ozok, Ahmet. 2010. *Fuzzy integrated vulnerability assessment model for critical facilities in combating the terrorism.* Expert Systems with Applications. 37. 3561-3573.

[11] R. Nateghi: 2018. *Multi-Dimensional Infrastructure Resilience Modelling: An Application to Hurricane-Prone Electric Power Distribution Systems* in IEEE Access, vol. 6, pp. 13478-13489, 2018.

Interconnections and interdependencies

Almost all infrastructure is connected to other infrastructure that is not directly in the control of the organisation that uses it. The criticality of an organisation's infrastructure can be very much affected by the other types of infrastructure that are connected to it (e.g. an element of a water supply network connected to a hospital).

Understanding the importance of the communities and other infrastructure providers that use infrastructure can provide assistance with a mature understanding of criticality.

Further information on interconnectedness and interdependencies is provided in the CIR Strategy Interconnectedness Guide.

Documenting criticality

The way to document criticality will vary by organisation, and largely be a function of available tools and resources.

Ideally, existing asset management or risk management systems would allow criticality to be recorded and integrated into organisation systems and processes. A new field or record may be able to be added to existing systems.

Because infrastructure assets, networks and systems are often geographical, integrating the information into a geographical information system (GIS) layer in existing toolsets proves useful, especially during outage response. For a sophisticated version of this please see the case study on Northern Beaches Council's stormwater criticality tool.

In the end, documenting criticality should be whatever is most useful for the organisation, and the other organisations whose infrastructure connects to it.

Reviewing criticality

Criticality assessments should be reviewed periodically to provide the most up-to-date picture of the operating environment. Changes to physical and logical infrastructure networks can have a large impact on criticality, as can the availability of alternate infrastructures or redundant components. Sometimes these changes are in connecting networks rather than the organisation's own network.

Changing conditions can necessitate reviews, where population growth, changing environment (e.g. updated climate change models), or aging of assets necessitates review.

A useful way to test the assumptions in a criticality model and facilitate a review is by conducting a table-top exercise to determine what might happen if key elements of an infrastructure network were unavailable. Having the right people attend these exercises, both from within and external to the organisation, can give key insights into how the model should be adjusted, and potentially facilitate useful and effective mitigation measures and enhanced emergency response.

Further reading

Fekete, A. 2011. Common Criteria for the Assessment of Critical Infrastructures. Int. J. Disaster Risk Sci. 2011, 2 (1): 15–24

Katina, P.F. and Hester, P.T. 2012. Systemic Determination of Infrastructure Criticality, Int. J. Critical Infrastructures, Vol. 9, No. 3, pp. 211-225

Criticality assessment examples

Some example assessments are supplied below.

Note that these examples are fictional and only serve as guide for organisations to understand and conduct their own criticality assessments.

These examples are deliberately broad – they do not address specific hazards, but only seek to understand the impact to the infrastructure service provided by understanding what happens if a part of the infrastructure network or system is unavailable.

These examples are also simplified to show what can be done with criticality assessment. Real assessments are likely to be assessing more complicated networks and criteria, but these examples illustrate a starting point to develop a better understanding of infrastructure networks.

In the examples where more criticality levels are required, for internal investment decisions, organisations could use their own 1-12 rating system, but for co-ordinating a response with other agencies to a large hazard, they could revert to the standard four terms to facilitate better understanding.

Real-world examples of criticality assessment are included within Case Studies.

Consequence of loss

Table 2: Fictional sample consequence of loss based on % of users impacted for state electricity supply

CIR Strategy criticality	Organisation criticality	Consequence (e.g. % of users impacted)	Context	Example asset or infrastructure network segment
Vital	1	>75%	State electricity supply	Large Electricity Generation Asset or Grid Connection
	2	60	State electricity supply	State Electricity Interconnector
	3	50	State electricity supply	
Major	4	40	State electricity supply	State Transmission Electricity Control Centre
	5	30	State electricity supply	Medium Electricity Generation Assets
	6	20	State electricity supply	Large Electricity Transmission Substations
Significant	7	15	State electricity supply	Smaller Electricity Generation Assets
	8	10	State electricity supply	Large Electricity Distribution Substations
	9	8	State electricity supply	Distribution Feeder connected to hospital
Low	10	5	State electricity supply	Electricity Distribution Feeder
	11	2	State electricity supply	Small Electricity Distribution Feeder
	12	1	State electricity supply	Low Voltage Electricity Distribution

The example above illustrates electricity supply loss criticality based on % of users within the state likely to lose supply. This does not model the NSW electricity delivery system closely, it is an example based on consequence of loss – in this case the percentage of total users without an infrastructure service.

This method is effective for very large networks, especially when making investment decisions around infrastructure resilience, and can provide focus for where high returns on resilience investments may be realised. This method can also help to prioritise resources when recovering from an outage.

Table 3: Fictional sample consequence of loss (% users impacted) for regional water supply

CIR Strategy criticality	Organisation criticality	Consequence (e.g. % of users impacted)	Context	Example asset or infrastructure network segment
Vital	1	100	Regional Water Service	Regional Water Treatment Plant
	2	75	Regional Water Service	Reservoir Supply Pumps
	3	60	Regional Water Service	Reservoir Supply Pipeline
Major	4	50	Regional Water Service	Wastewater Treatment Plant
	5	40	Regional Water Service	Dam Supply Pipeline
	6	30	Regional Water Service	Stormwater Trunk Drain
Significant	7	20	Regional Water Service	Wastewater Pumps
	8	15	Regional Water Service	Stormwater Swales in Large Suburban Area
	9	10	Regional Water Service	Large Stormwater Drains
Low	10	7	Regional Water Service	Small Booster Pumps
	11	5	Regional Water Service	Small Wastewater Pumps
	12	2	Regional Water Service	Small Stormwater Drains

The example above illustrates several types of water infrastructure service loss in a region (based on the size of a regional local government area).

It contrasts the example of state electricity supply to show that criticality should be assessed from the perspective of the organisation who owns and/or operates the infrastructure service.

Percentage of users affected is particularly useful here, as total number of users without supply may not illustrate how critical an outage could be to the service area, especially should external assistance at the regional or state level be required to help restore supply.

This method is also effective when making investment decisions around infrastructure resilience as it spans the assets owned be a specific organisation, such as a regional council or larger water service supplier.

Table 4: Fictional sample consequence of loss (number of users impacted) for state road network

CIR Strategy criticality	Organisation criticality	Consequence (e.g. number of users impacted / day)	Context	Example asset or infrastructure network segment
Vital	1	100,000	State road network	Princes Highway
	2	80,000	State road network	M1 Pacific Motorway
	3	50,000	State road network	Hume Highway
Major	4	30,000	State road network	Parramatta Road
	5	25,000	State road network	Epping Road
	6	20,000	State road network	Great Western Highway
Significant	7	15,000	State road network	Blacktown Rd
	8	10,000	State road network	A32 Mitchell Highway
	9	5,000	State road network	Cessnock Road
Low	10	2,000	State road network	Newell Highway
	11	1,000	State road network	Monaro Highway
	12	<500	State road network	Local Roads

The example above illustrates consequence of loss based on number of users. It contrasts well against the other mechanisms for transport, because it is more easily communicated to stakeholders outside the transport industry and allows more rapid understanding of the consequence.

This method is also effective for very large networks, and when making investment decisions around infrastructure resilience, based on returns against number of infrastructure users.

With more advanced spatial modelling to estimate how users might take alternative routes and how much time that might add to a trip, economic consequences can be estimated for business and communities and again assist with infrastructure resilience and hazard mitigation investment decisions.

Time and velocity based on infrastructure interconnection

Table 5: Fictional sample consequence of loss based on remaining time that infrastructure can provide service without interconnected infrastructure (in this case water supply without electricity supply)

CIR STRATEGY criticality	Organisation criticality	Hours of operation without electricity supply	Context	example asset or infrastructure network segment
Vital	1	4	Regional water service	Water Treatment Plant (75% supply)
	2	6	Regional water service	Flood mitigation / overflow pumps
	3	8	Regional water service	Water Treatment Plant (25% supply)
Major	4	12	Regional water service	Wastewater Treatment Plant (without holding dam)
	5	16	Regional water service	Flood mitigation / overflow pumps with cutover switch for mobile generator
	6	24	Regional water service	Large wastewater pumps
Significant	7	32	Regional water service	Wastewater Treatment Plant (with holding dam
	8	40	Regional water service	Small wastewater pumps
	9	48	Regional water service	Dam Supply Pipeline (dam at low levels)
Low	10	72	Regional water service	Water Treatment Plant (25% supply) with backup generator
	11	96	Regional water service	
	12	168	Regional water service	Dam Supply Pipeline (dam at high levels)

Time to continue operation without external assistance can be a very useful metric for assessing criticality, especially when dealing with upstream supply service providers.

Sharing this information with upstream providers can be particularly effective for emergency response and can form the basis for a shared exercise to increase emergency preparedness.

Ability to provide quality and/or quantity and complex scenarios

Table 6: Sample consequence of loss based on reduced service quality or quantity

CIR Strategy criticality	Organisation criticality	End user actions	Context	Example asset or infrastructure network segment
Vital	1	Function without electricity	state electricity supply	State wide Black System Event
	2	Mass load shedding	state electricity supply	Unable to serve 50% of State Electricity
	3	Mass load shedding	state electricity supply	Unable to serve 20% of State Electricity
Major	4	Shed large loads (mines, smelters etc.)	state electricity supply	Unable to serve 10% of State Electricity
	5	Shed large loads	state electricity supply	Unable to serve 7.5% of State Electricity
	6	Shed large loads	state electricity supply	Unable to serve 5% of State Electricity
Significant	7	Public reduces air conditioning	state electricity supply	Unable to serve 2.5% of State Electricity
	8	Public reduces air conditioning	state electricity supply	Unable to serve 1% of State Electricity
	9	Local reductions (automated load control)	state electricity supply	Unable to serve a suburb
Low	10	No action	state electricity supply	Unable to serve a distribution feeder
	11		state electricity supply	
	12	No action	state electricity supply	Unable to serve a small number of users

The scenario above assumes a disruption to the capacity of the electricity delivery network to supply the full amount of energy at a state level. In reality, this would require significant co-operation between state asset owners and federal regulatory bodies to restore, however it serves to illustrate potential infrastructure end-user actions.

One way to manage this situation is to promote different infrastructure user actions to assist with most urgent supply and staged restoration of services.

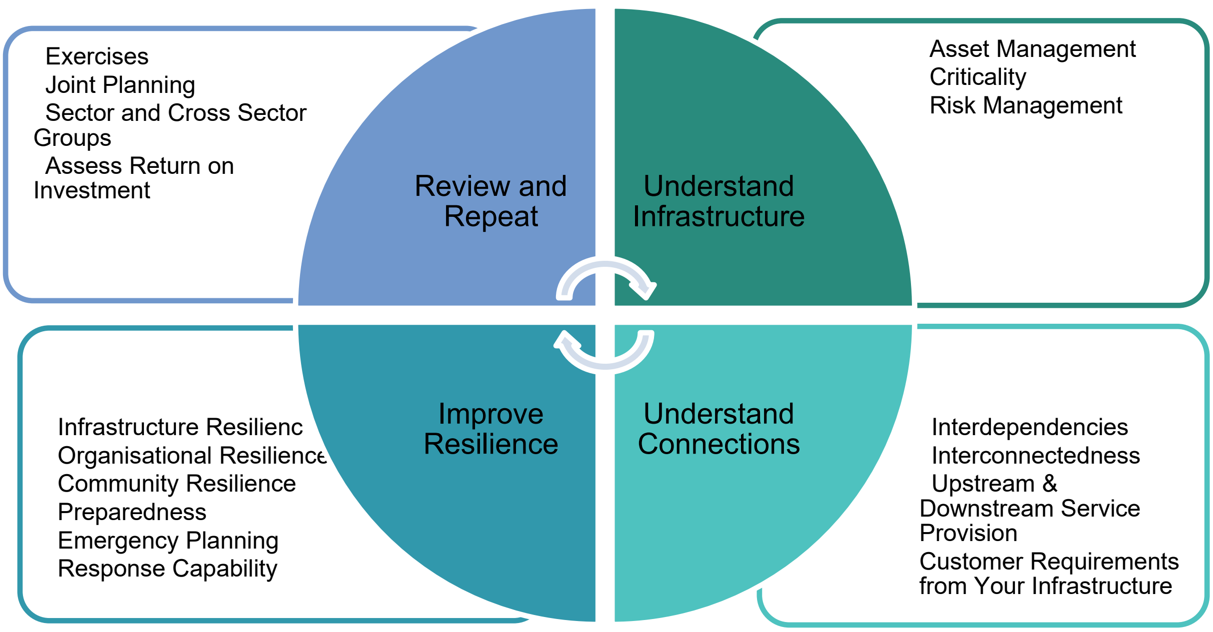
This scenario type applies to other infrastructure services as well (e.g. end users boiling water before use, reduced number of hospital patients serviced with redirection of ambulances)

Using criticality to increase infrastructure resilience

Criticality assessments are part of a larger effort to improve infrastructure resilience, organisational resilience and community resilience.

Where resources are limited, criticality assessment allows infrastructure providers to focus on what is most important in the provision of their infrastructure service.

Any resilience improvement is a maturity journey and can be represented in a cycle, where criticality enhances understanding of your infrastructure, which will aid other connected infrastructure providers and users to better understand your, and their own, infrastructure.



Infrastructure resilience is generally about building and supporting infrastructure against a variety of threats and hazards for continued service. In this way it mirrors the all-hazards approach of emergency management where consequences are considered against a variety of threats, rather than the sometimes single-focused view of standard risk assessment.

More information around improving infrastructure resilience is included within the infrastructure design, construction and operations guides, and in industry-specific guides, available on the opengov website.

Criticality enables a strategic view

All organisations are already assessing the criticality of their infrastructure assets whether this is a formal process or not. Formalising assessment allows better communication of results, negates potential single points of failure when staff are absent, and considers larger system-level resilience. With some form of formal prioritisation, criticality is typically guided by intuition or expert judgement, which may miss critical components at a system level.[12]

At the executive level, formalised criticality assessments can provide inputs into high-level decision making around how activities, budgets and people contribute to the desired outcomes of an infrastructure service organisation and how to achieve those outcomes more effectively and efficiently.[13]

Where an organisation operates a large primary infrastructure network (e.g. electricity or water supply) criticality can also assist in considering impacts associated with secondary or supporting systems, such as SCADA, communications, and information technology systems. This allows the consideration of resilience enhancements at a system level rather than focusing on a single set of infrastructure.

Criticality for asset management

Criticality assessment can serve both strategic and operational asset management.

Strategic asset management can assist with resource allocation, whether that be planning effort, capital investment in infrastructure, or long-term maintenance programs of infrastructure. It can become a significant factor in prioritising large programs of work.

Operational asset management can use criticality during response to outages and service restoration, and to prioritise resource allocation during normal operational activity.

Criticality can assist decision-making across all phases of the asset management cycle (Planning, Design, Construction & Operation)

Criticality for emergency management

Once criticality in an infrastructure network is understood it can be useful across all aspects of the emergency management cycle (Planning, Preparedness, Response and Recovery).

Used primarily for prioritisation of resources, criticality can aid the speed and effectiveness of an emergency response and ensure infrastructure services are available to communities and other infrastructure providers sooner. It can also assist multi-agency response, where local emergency services have a good understanding of the most critical parts of physical infrastructure networks, they can assist in protecting them from threats and hazards.

During planning and preparedness phases, criticality aids the investment of time in co-ordination and exercising.

---

[12] 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).

[13] Willis, Henry H. and Kathleen Loa. 2015. *Measuring the Resilience of Energy Distribution Systems*, RAND Corporation. Available at www.rand.org/pubs/research_reports/RR883.html

Criticality for security and critical infrastructure protection

Owners of critical infrastructure are responsible for the ongoing security of their infrastructure against malicious threats.

This is especially important for infrastructure networks digitally connected to outside networks. The increasing frequency, scale, sophistication, and severity of cyber-attack make it difficult to protect a connected network from all threats[14], but prioritisation of services can assist with improved defence for the most critical systems.

Critical infrastructure protection (CIP) focuses on mitigation against the specific threat of terrorism for infrastructure determined to be critical to the state. [15] CIP minimises vulnerability to criminal or malicious threats via physical, procedural, person-based, and electronic defences.

In NSW the protection of CI from terrorism is managed under separate and existing arrangements. The NSW Police Force is the combat agency for terrorism. The Critical Infrastructure Protection Program and Critical Infrastructure Resilience Strategy are complementary to each other.

Further advice

Contact Resilience NSW, your Local or Regional Emergency Management Officer, or your CIR Strategy Sector or Cross-Sectoral Group for assistance with criticality assessment, ideas for mitigation projects to build infrastructure resilience, or to assist with joint exercises or scenarios.

Further reading

D. Marcelo, S. House, A. Raina. 2018. *Incorporating Resilience in Infrastructure Prioritization: Application to the Road Transport Sector*. World Bank Policy Research Working Paper 8584.

Willis, Henry H. and Kathleen Loa. 2015. *Measuring the Resilience of Energy Distribution Systems*, RAND Corporation.

Australia New Zealand Counter Terrorism Committee. National Guidelines for Protecting Critical Infrastructure from Terrorism.

Case Studies included as part of this guide highlight ways to use criticality assessments to strengthen the security and resilience of infrastructure.

[14] Australian Cyber Security Centre. 2017. 2017 Threat Report.
[15] https://www.secure.nsw.gov.au/what-we-do/working-with-nsw-businesses/

Appendix A: Case studies

Case study: Northern Beaches Council: stormwater asset criticality

northern beaches council

Northern Beaches Council has developed sophisticated tools to understand the criticality of all elements of their stormwater drainage system. The council used multiple criteria to assess the criticality of its stormwater assets including but not limited to:

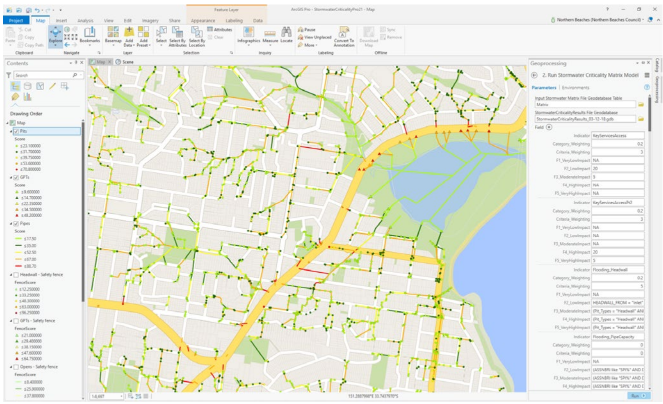
- Asset size
- Depth of assets
- Proximity to arterial, collector and regional roads
- Proximity to buildings and critical utilities
- Proximity to community facilities, medical, aged and child care and emergency services
- Land use zonings and contaminated land
- Classification of receiving waters

The criteria are weighted based on impact to social, economic, and environmental concerns.

Council's asset data system provided the base data, which was then integrated with existing asset spatial data sets in Council's ArcGIS geographical information system. All data was also given a confidence rating based on how accurate it was perceived to be.

An attribute field for criticality is embedded within the asset register and as the GIS model matures, the risk scores will be recorded and updated back into the asset register. Assets can be colour-coded on maps to display their criticality risk scores. This assists in:

- Highlighting vulnerable locations;
- Storm hazard preparedness and planning;
- More efficient and effective pre-storm maintenance inspections;
- Prioritisation of condition monitoring and
- Prioritisation of investment in upgraded or new stormwater infrastructure.



With the criticality data represented as a map in council's GIS, specific hazards such as overland flooding can be integrated to provide targeted risk assessment and further assist council to prioritise investment in critical areas. Longer-term impacts such as climate change and population growth, can now also be considered.

Assets can have their inspection frequency adjusted based on criticality, with the inspections completed in-the-field on mobile devices which write directly back into the asset register. Northern Beaches is proving that good processes and data enables good decisions. An enhanced picture of criticality is allowing a more efficient and effective stormwater drainage system, which reduces risk to life and property and builds further resilience in protecting council and community assets and infrastructure.

Case study: Assessing criticality in New Zealand lifelines vulnerability assessment

The New Zealand Lifelines Council is undertaking a national assessment of the vulnerability of critical infrastructure (lifelines infrastructure) based on member inputs.

The assessment is designed to:

- provide strategic oversight of infrastructure services;
- raise awareness of interdependencies and;
- contribute to improving resilience.

A multi-layered approach to criticality is used including:

- Geographic: to determine if infrastructure is nationally, regionally or locally significant
- Consequence of loss of single sites: “Pinch points” in sector supply chains
- Consequence of loss of connecting assets: “Lineal pinch points” such as major roads or transmission lines
- Consequence of loss of service: number of people affected

The report also assesses geographic interdependency via infrastructure hotspots where multiple classes of assets converge in a single location. Understanding the interdependencies can help drive collective projects for infrastructure providers.

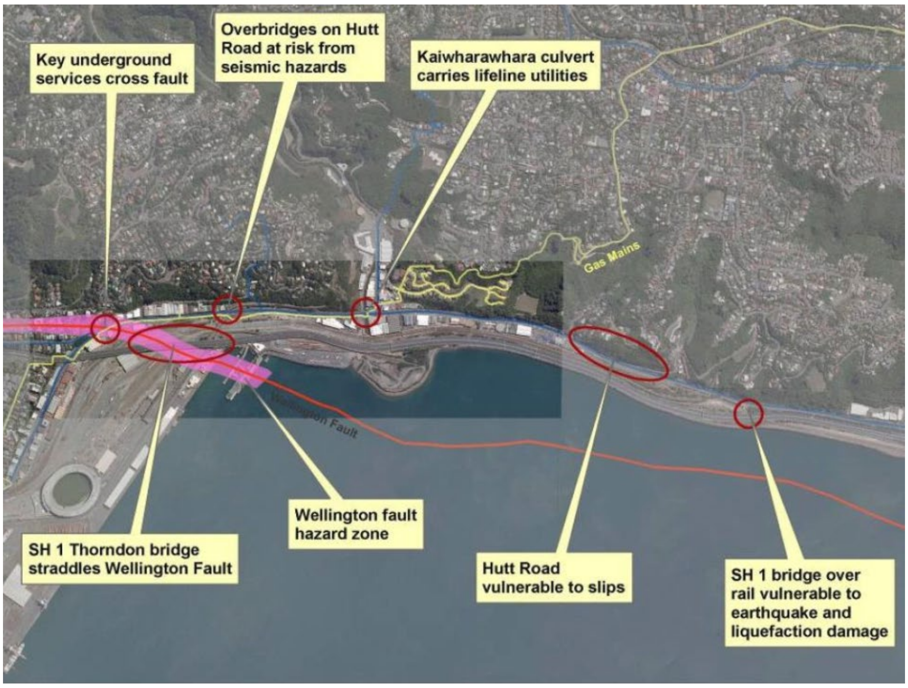


Figure 4: Infrastructure Hotspot in Thorndon, Wellington

Major hazards are also considered with a view to building resilience into infrastructure networks and the assessment recommends several projects to support ongoing infrastructure resilience in Zealand.

[Stage 1 of the vulnerability assessment is available through the NZ Lifelines Council]

Case study: Using criticality for service restoration: Townsville City Council and Ergon Energy

Water and electricity providers in North Queensland are collaborating to assess criticality and prioritise service restoration to minimise disruption to critical infrastructure services.

Townsville City Council created an inventory of its water and wastewater assets in a bid to understand what assets needed to be restored first, in the event of a service interruption.

Priority levels are based on the time that water and wastewater assets can be without electricity supply before service becomes affected:

- Priority 1 (Vital) assets should be restored within 4 hours
- Priority 2 (Major) assets should be restored within 8 hours
- Priority 3 (Significant) assets should be restored within 24 hours
- Low Priority assets are not listed

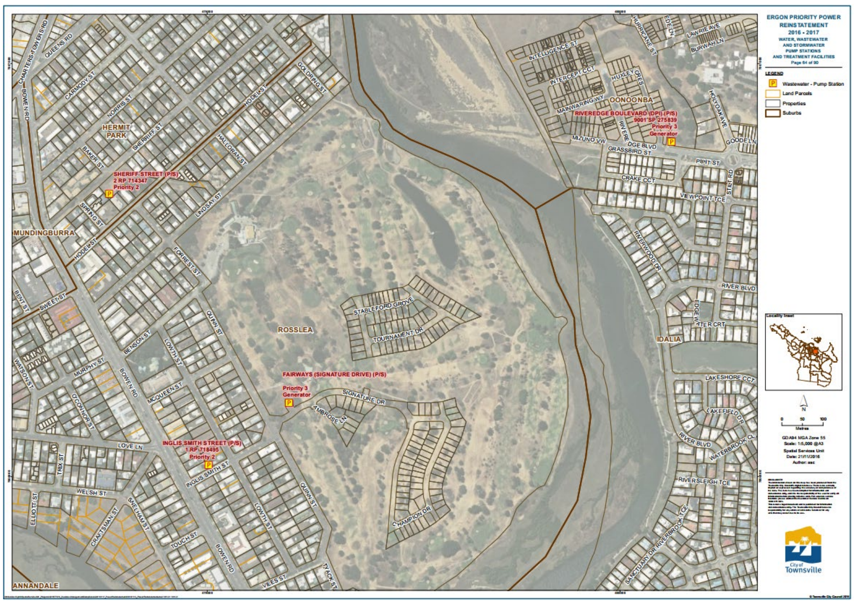
		Asset Information							Ergon Information		
MAP NO.	REF NO.	PUMP STATION/PLANT NAME	GENERATOR PRESENT	PRIORITY	PRIORITY 2 (SUB CATEGOR	TYPE	EASTING	NORTHING	Sub	Feeder/Section	DEPT
67	P/S AA1	TOMKINS STREET/BRUCE HIGHWAY (CLUDEN)	NO	2	2.5	P/S	481111.1	7863101.4	TV1111111	SYD-10	WW
67	P/S AA2	ABBOTT STREET CLUDEN	YES	3		P/S	481112.1	7863102.4	TV1111112	SYD-11	WW
68	P/S AA3	BECK ROAD	NO	2	2.6	P/S	481113.1	7863103.4	TV1111113	SYD-12	WW
68	P/S AA4	CHELSEA DRIVE	NO	2	2.6	P/S	481114.1	7863104.4	TV1111114	SYD-13	WW
68	P/S AA5	MOUNT MARGARET PS	NO	2	2.0	P/S	481115.1	7863105.4	TV1111115	SYD-14	WATER
68	P/S AA6	GOLF LINKS DRIVE (COWBOYS STADIUM)	NO	2	2.6	P/S	481116.1	7863106.4	TV1111116	SYD-15	WW
68	P/S AA7	CANTERBURY ROAD	NO	2	2.7	P/S	481117.0	7863107.4	TV1111117	SYD-16	WW
68	P/S AA8	RIVIERA CIRCUIT	NO	2	2.6	P/S	481118.0	7863108.4	TV1111118	SYD-17	WW
69	P/S AA9	BOWHUNTERS ROAD	YES	3		P/S	481119.0	7863109.4	TV1111119	SYD-18	WW
69	P/S AA10	CARLYLE GARDENS (SMITH ROAD)	NO	2	2.4	P/S	481120.0	7863110.4	TV1111120	SYD-19	WW
69	P/S AA11	VICKERS ROAD	NO	2	2.6	P/S	481121.0	7863111.4	TV1111121	SYD-20	WW
70	P/S AA12	SHEERWATER DRIVE	NO	2	2.5	P/S	481122.0	7863112.4	TV1111122	SYD-21	WW
70	P/S AA13	MORLEY STREET	NO	2	2.1	P/S	481123.0	7863113.4	TV1111123	SYD-22	WW
70	P/S AA14	FRESHWATER DRIVE	NO	2	2.2	P/S	481124.0	7863114.4	TV1111124	SYD-23	WW
71	P/S AA15	ABC Facility	NO	1		WTP	481125.0	7863115.4	TV1111125	SYD-24	WATER
71	P/S AA16	PONTI ROAD PS	NO	3		P/S	481125.9	7863116.4	TV1111126	SYD-25	WATER

Figure 1: Water asset criticality data (information is for illustrative and indicative purposes only)

Since the initial inventory, projects have been completed or are planned to improve the resilience of water assets in the Townsville City Council area. Updates are provided prior to storm season so that pre-emptive emergency and restoration plans can be updated.

The asset data information is converted to a geospatial layer to provide asset location maps.

These maps can be used for emergency planning, exercises, and developing a restoration plan during an emergency response.



Appendix B: 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)
CIR Strategy	NSW Critical Infrastructure Resilience Strategy
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
GIS	A geographic information system (GIS) is a framework for gathering, managing, and analysing spatial and geographic data.
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.
NSW	New South Wales
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 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)