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Guidelines for Resilience in Infrastructure Planning: Natural Hazards



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1 INTRODUCTION

1.1 Purpose

Natural disaster risks, a growing population and increasing interdependencies between infrastructure systems reinforce the need to improve the resilience of the State's infrastructure, particularly infrastructure that supports essential community services. Failure to adequately address infrastructure resilience puts existing and future assets at risk. This may impose significant economic and social costs on the community, while also increasing the costs to government of repairing or replacing damaged assets.

Climate change is expected to increase temperatures and alter the frequency and intensity of extreme weather events such as heatwaves and flooding. This is likely to increase the vulnerability of NSW's infrastructure to natural hazard risks. Damage to one asset may impact on other assets, affecting their capacity to provide services. It is therefore essential that agencies consider the vulnerability of existing and new infrastructure to these risks.

This guidance is designed to provide high-level support to those undertaking infrastructure planning and design to ensure infrastructure investments deliver appropriate levels of resilience. It includes information on how to embed consideration of resilience into decision making — through the identification, planning, appraisal and ongoing management of policies, programs and projects.

This guidance focuses on building resilience to **natural hazards risks**, which are likely to be exacerbated by climate change. Many of the concepts explored in this guidance are also relevant for an assessment of infrastructure resilience to a wider set of risks. Assessing these risks requires good data and information, utilising experience and expertise in government and agencies. References are provided to resources that can practically support agencies. As the evidence base develops over time these guidelines and associated resources will be updated.

It is intended that this guidance is read in conjunction with the [NSW Government Business Case Guidelines \(TPP18-06\)](#) and the [NSW Government Guide to Cost-Benefit Analysis \(TPP17-03\)](#). **Table 1** summarises the links between this guideline and the business case guidance.

1.2 What is resilient infrastructure?

Resilient infrastructure can be defined as infrastructure that is capable of:

- **Withstanding disruption** so it can continue to operate in the face of shocks and stressors
- **Adapting** to changing circumstance as uncertainties are resolved i.e. incorporating flexibility to be modified as circumstances change.¹

Infrastructure investments usually involve large and irreversible investments with long asset lives, which makes consideration of resilience particularly relevant. **Box 1** below provides some other useful definitions related to resilience.

¹ Adapted from Infrastructure NSW (2018), *State Infrastructure Strategy 2018-2038: Building Momentum* and Lloyd's of London and Arup (2017), *Future Cities: Building infrastructure resilience*

Box 1: Useful definitions

[The NSW Critical Infrastructure Resilience Strategy](#) provides several useful definitions that are important for understanding infrastructure resilience. For example:

- **Hazards** include extreme weather events, equipment failure and accidents.
- **Shocks** are defined as sudden, sharp events that have the potential to disrupt services supplied via infrastructure.
- **Stresses** include longer term, broader trends like climate change. These can amplify shock events or exacerbate hazards.
- A **risk**² is a function of the:
 - **likelihood** that any hazard will cause harm under a given scenario and
 - **consequence** or the extent to which the system, environment, economy and society might be adversely affected under this scenario.

Risk is not the same as uncertainty. [NSW Government Cost-Benefit Analysis Guidelines](#) explains:

- **Risk** is where the probability of alternative future outcomes can be reasonably estimated.
- **Uncertainty** is where future outcomes themselves are unknown and therefore have unquantifiable probabilities.

Other useful definitions for this guideline include:

- **Materiality** is an impact or dependency on a natural hazard is material if consideration of its value, as part of a broader assessment for decision making, has the potential to alter that decision.³
- **Interdependencies** are where two or more pieces of infrastructure are either partially or wholly reliant on each other to operate effectively.

Given that this guideline focuses on natural hazards, and the extent to which climate change affects those risks, it is worthwhile understanding that key natural hazards include hotter temperatures and heatwaves, flooding and tidal inundation, seawater rise and coastal erosion, and increasing severity and frequency of fire.

There are broadly **two types of infrastructure** to which resilience considerations should be applied during infrastructure planning.

The first is infrastructure specifically aimed at managing or mitigating the impact of natural hazards (referred to in the remainder of this guideline as **natural hazard infrastructure**). Constructing sea walls to better withstand impacts of rising sea levels for coastal communities is one such example. Sea walls are constructed with the specific primary objective of reducing the likelihood or consequence of a natural hazard.

² Note: there may be other definitions of risk elsewhere in infrastructure planning and delivery.

³ Definition adapted from Natural Capital Coalition's Natural Capital Protocol.

The second is infrastructure with primary objectives other than managing or mitigating natural hazards (hereafter referred to as **other infrastructure**). Other infrastructure – which constitutes most public investments – could also be directly or indirectly affected by natural hazards. Considering the impact of natural hazards in the planning or risk management process for other infrastructure will ensure government investment is targeted at quality infrastructure that can withstand natural hazards and remain operable, delivering better value for money for the community. For example, a road network augmentation could be designed to improve transport network outcomes while also minimising flooding risk for a community.

This guidance distinguishes between these two types of infrastructure where relevant.

1.3 When does resilience need to be considered?

It is important government agencies consider resilience from the earliest stages of infrastructure planning, including the problem definition that informs the initial assessment of infrastructure requirements to meet community needs, to option identification and assessment, and through the life of an asset including within asset management processes. Resilience should be considered for projects, policy or program including place-based programs. The level of detail should continually be refined as the project progresses through different stages of the business case development, design delivery and operations. This is outlined in **Table 1** below.

1.4 Key principles

Key principles to keep in mind when incorporating resilience into infrastructure decision making are:

- **Collaborative:** Natural hazards are broad in scope and require a collaborative approach, drawing on multidisciplinary experts across agencies and Government.
- **Targeted:** Resilience considerations should be targeted at natural hazards which are specific and relevant to the infrastructure and its location.
- **Consistent:** A consistent approach should be taken to the identification natural hazards, and the assessment of natural hazards between options.
- **Continuous and adaptive:** Natural hazards evolve over time. This means resilience needs to be considered and re-evaluated not only in infrastructure planning, but across the asset lifecycle.
- **Proportionate:** The level of consideration, and likely investment, in resilience should be proportionate to the scale of the infrastructure, size of the natural hazard risk and the extent of interdependencies.
- **Comprehensive:** Resilience infrastructure requires consideration of all relevant costs and benefits, including those that may extend beyond the jurisdiction of the relevant agency.

This guideline is structured around the key steps required to embed resilience in infrastructure decision making:

- **Considering natural hazard risks early** in infrastructure planning (see Section 2).
- **Identifying a broad range of options** with due consideration of natural hazard risks and uncertainties (Section 3).
- Systematically **appraising and evaluating risk and uncertainty** to inform decision making (Section 4).

- **Monitoring and re-evaluating** natural hazard risks over the life of infrastructure assets (Section 5).

Table 1: Overview of key actions to incorporate resilience considerations in infrastructure planning

NSW GOVERNMENT BUSINESS CASE GUIDELINES STAGE	RESILIENCE CONSIDERATIONS
Stage 0: Problem Definition	<ul style="list-style-type: none"> ▪ Natural hazard infrastructure should outline this in the problem definition stage of a business case. This requires: <ul style="list-style-type: none"> ▪ An initial assessment of the relevant natural hazards and climate scenario/s being considered. ▪ An explanation of the relevance and materiality of addressing the natural hazard risk. ▪ Other infrastructure should consider resilience in developing the strategic responses or options.
Stage 1: Strategic Business Case (options analysis, Stage 1 cost benefit analysis)	<ul style="list-style-type: none"> ▪ All infrastructure projects should identify the key risks and uncertainties at this stage. This includes understanding the future climate scenario/s which should be incorporated into the base case and options. ▪ Options for improving resilience from the base case could involve non-build solutions, build interventions and adaptive responses. ▪ In the Stage 1 cost benefit analysis, the costs and benefits associated with resilience should be considered for the base case and each option.
Stage 2: Detailed Business Case (options selection and Stage 2 cost benefit analysis)	<ul style="list-style-type: none"> ▪ Resilience should form part of the detailed analysis to identify a preferred infrastructure investment which is put forward for funding. ▪ Analysis to reach a preferred option should include appropriate quantification of risk and uncertainty. There are a range of methodologies which can be used to do this. ▪ Analysis should include material impacts driven by natural hazards and should include economic, environmental and social impacts.

2 EARLY CONSIDERATIONS

Key points:

- Improving infrastructure resilience to natural hazards should be considered early in the development of all infrastructure proposals.
- Early consideration requires an initial assessment of the relevant natural hazards, based on existing resources and expert advice, to identify whether further analysis is required.

Ensuring resilience considerations are included in the problem definition stage of infrastructure planning can influence the direction of interventions and investment. It is therefore important to consider the relevant natural hazards at this early stage to ensure problems related to resilience are identified.

2.1 Future natural hazards scenarios

The first step to improve infrastructure resilience is understanding the vulnerability of the infrastructure, that is extent and nature of the relevant natural hazards to which the investment could be exposed and the possible consequences of this exposure to this hazard. Identifying exposure requires understanding of:

- The extent to which the proposed investment may be affected by **existing natural hazards**.
- The **impacts of climate change** and how it may exacerbate future exposure to existing natural hazards.
- Threats resulting from **interdependencies** with other infrastructure that is also exposed to natural hazards. (see Appendix A for further information).
- Interactions between natural hazards with existing environmental risks on the land. For example, coastal inundation may exacerbate the impacts of existing soil contamination as contaminants could be mobilized and redistributed to adjoining waterways.
- Identifying the consequences, including understanding **the frequency, duration and severity of the resulting disruption** to businesses and the community and the cost of the impact or failure of the asset.

As a first step an initial assessment is usually sufficient to determine the extent to which natural hazards could affect a potential infrastructure investment, now and in the future. This can then help determine whether more detailed analysis is required. If the risk appears to be significant enough to change the nature of the investment — for example changing the location of the infrastructure — more detailed analysis may be required. In other cases, this more detailed assessment would be used to develop, evaluate and assess resilience options (see Section 3). **Box 2** presents a case study about the natural hazard risks that were considered during the planning for Sydney Metro, and the identified responses.

Box 2: Case study – Sydney Metro

Sydney Metro is Australia's biggest public infrastructure transport project. Through understanding asset risks and vulnerabilities in the short (2030), medium (2070) and long-term (2100), Sydney Metro has been able to build climate resilience into the metro railway network. Sydney Metro projects undertake climate risk assessments through the lens of these time horizons and widely available climate change models from early stages of project development. This has enabled Sydney Metro to understand potential climate risks, vulnerabilities and impacts, and to determine appropriate management and mitigate measures during construction and operation.

Flooding, extreme weather and heat wave events have been identified as the most relevant climate risks for Sydney Metro. Early on in planning and business case development it was determined that these risks could best be addressed with design and engineering solutions. These risks have fundamentally shaped the engineering response, such that:

- the potential increase in rainfall intensity and severe weather events has informed station and drainage designs, to ensure the safety of customers and continuous operation.
- equipment that is critical to the safe and continuous operation of Sydney Metro projects are housed in dedicated temperature-controlled rooms that are designed to deal with extreme ambient temperatures.
- ventilation systems for tunnels and stations are designed to maintain customer comfort during hot summer days well into the future.
- the air conditioning units on trains are designed to cope with extreme ambient temperatures and maintain customer comfort.
- to help prevent localised flooding and controlled discharge, permeable surfaces make up the majority of the Sydney Metro Trains Facility. This allows rain to sink into the ground, and native vegetation is also planted where operational requirements allow.

Source: Sydney Metro

It is important to note that exposure to natural hazards is often expressed in terms of probability, with rarer (lower probability) hazards sometimes having the greatest consequences. Understanding vulnerability of infrastructure to hazards usually involves combining the probability of the hazard occurring with the range of consequences that are possible. Thresholds for acceptable risk may be different for different types of infrastructure. Typically, the more critical the infrastructure, the lower the level of acceptable risk. The acceptable level of risk should be agreed at an organisational level.

2.2 Informing vulnerability risk assessment

There are a range of resources available to support consideration of natural hazards in infrastructure planning. Appendix B provides contact details for relevant experts and data sources.

Expert advice on existing natural hazard risks and climate change impacts is available from the Office of Environment and Heritage and the Adapt NSW website. Expert advice on potential interdependencies may be sought from infrastructure operators and maintenance staff for similar existing infrastructure. As interdependencies often concern utilities such as electricity and water, it is often also useful to seek advice from these providers (as discussed in **Box 3**).

Box 3: Cross-Dependency Initiative

A platform being developed in NSW through the Cross-Dependency Initiative (XDI), allows for analysis of climate risks at an asset level, and identifies risks arising from interdependencies with other infrastructure. For example, a wastewater treatment plant may be reliant on power supply from a single electricity sub-station and on access via a single road.

The XDI also supports the analysis of different resilience investment options and allows the user to test different adaptation pathways under different climate change and hazard scenarios. The platform is currently being trialled for the Greater Sydney region by the Office of Environment and Heritage with a number of agencies and the City of Sydney. For more information see www.xdi.com.

Source: INSW

Existing natural hazard datasets available to agencies are summarised in the [Common Planning Assumptions Book](#). The book includes guidance on using climate projections for infrastructure planning. The guidance refers to the [NSW and ACT Regional Climate Modelling](#) (NARClIM) data set as a starting point. It contains climate projections for south-east Australia at a 10-km resolution. NARClIM provides projections from a suite of models which span a range of likely future changes in climate across NSW.⁴ Other sources of climate change impact information include the [Australian Government's Climate Change in Australia](#). Using this information, a range of possible climate scenarios should be developed to explore the extent of the possible impacts of climate change on natural hazards and range of consequences.

Key steps

- Conduct an initial scan of whether a proposal may be affected by current or future natural hazard risk.
- Ensure you have consulted experts to undertake a vulnerability assessment on relevant natural hazard risks, the possible consequences and any pertinent broader factors such as interdependencies and climate change.

Outcome

- Key climate change and natural hazard risks are considered early in the infrastructure planning and business case processes.

⁴ Note: NARClIM is currently being updated.

3 RESILIENCE OPTIONS

Key points:

- Options for improving resilience to natural hazards from the base case should involve a “do nothing” option, non-build solutions, build interventions and adaptive options.
- Adaptive decision making, which in this context involves adopting a flexible investment strategy for infrastructure projects, is a suitable approach where there is significant uncertainty around future natural hazards or climate change and where more information will be available in the future to inform decisions.

A key element of delivering resilient infrastructure is identifying a broad range of options during the planning stage which factor in potential natural hazard risks.

3.1 Value of flexible, adaptive approaches

The resilience of infrastructure investments can be improved by reducing the likelihood and/or consequence of an investment’s exposure to natural hazards or climate change. Where there is significant uncertainty about future conditions and where better information will be available in the future to reduce uncertainty, pursuing a flexible or adaptive investment strategy is likely to offer better value for money than pursuing a fixed plan based on assumed future conditions. This involves staging decision-making, often referred to as adaptive decision-making, to allow better information about material uncertainties including natural hazard risks to be incorporated into future investment decisions. Another way of describing this is as a move away from a linear traditional decision process with a single investment decision to a more iterative adaptive management approach (shown in **Figure 1**). Under adaptive management, multiple investment decisions are made over time based on ongoing monitoring and assessment of natural hazard risks. In practice this may involve deferring decision-making until better information becomes available, or ensuring decisions build in optionality or adaptive capacity. An example of adaptive decision-making is described in **Box 4**.

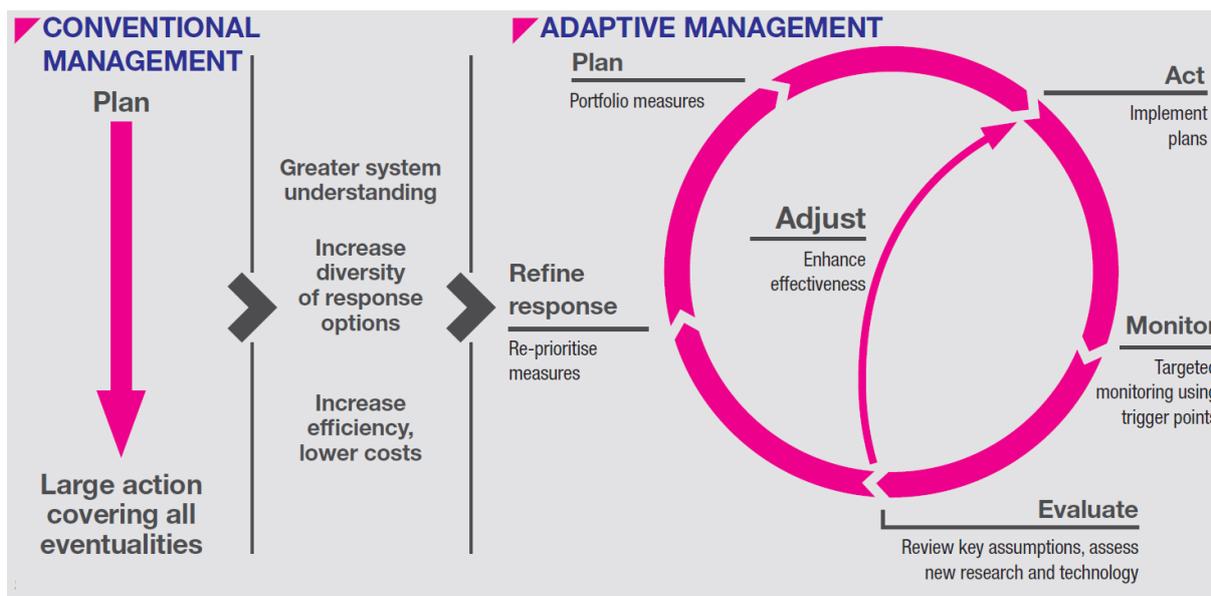


Figure 1: Conventional vs adaptive management

Source: Infrastructure NSW (2018), State Infrastructure Strategy 2018-2038

Box 4: Case Study – Pacific Highway Upgrade

NSW Roads and Maritime Services (RMS) took a staged adaptation approach to the Pacific Highway upgrade (Woolgoolga to Ballina). RMS's Pacific Highway Design Guidelines have a target of 1 in 100-year flood immunity for upgrade projects, except on major flood plains where a minimum 1 in 20-year flood immunity is adopted (a 1 in 100-year flood immunity is defined as there being a 1 per cent probability a flood event would disrupt the operation of the asset). Where immunity was less than 1 in 100 years, mitigation strategies were considered through a cost benefit analysis. In setting the flood targets, RMS considered the strategic value of the highway and the potential for significant urban areas to be isolated in the event of flooding.

The design guidelines required climate change sensitivity testing of the 1 in 100-year immunity, which showed while contemporary road embankments met the flood targets, the embankments may need to be raised by up to 0.2m to protect against flooding from future sea level rises. As the design guidelines emphasised the role adaptive management as an alternative to build options, RMS decided to defer this investment, recognising road pavements require periodic rehabilitation every 30-40 years, by which time improved data would be available on sea level rises. This rehabilitation could include raising the pavement by 0.2m without substantial changes to the road design. This meant that the capital expenditure required to adapt to future climate change would be outlaid closer to the required time. RMS did, however, widen the highway boundary by up to 1.6m in places to accommodate future increases in embankment height (allowing for a batter slope of 1:4). Source: INSW and RMS

3.2 Adaptation and resilience options

Infrastructure and service planners should develop and assess a broad set of options that reflect the materiality of natural hazard risks identified in Section 2.1. For natural hazard infrastructure, the

options developed should focus on responding to these risks, whereas for other infrastructure, the options developed should primarily focus on addressing the underlying problem, whilst having regard to key natural hazard risks.

A **multidisciplinary workshop** is a useful mechanism for identifying a wide range of potential options to improve infrastructure resilience. This workshop could include the business case proponent, asset managers, risk specialists, sustainability specialists and relevant infrastructure specialists.

As noted above, options developed should include a “do nothing” option, non-build solutions (which may focus on behavioural change), build interventions and adaptive options. More specific elements to consider within options include:

- **Seeking opportunities to avoid risk altogether.** This may entail relocating infrastructure away from a hazard, for example through changes in land use planning which can prevent or reduce the likelihood of hazards impacting on communities.
- **Building in adaptive capacity,** to ensure infrastructure assets can be adapted or modified over time as uncertainties are resolved. Adaptive capacity can also relate to operational efficiencies and flexibility (e.g. the ability for software updates to make a renewable energy asset operate more efficiently).
- **Managing demand,** by optimising the use of existing infrastructure capacity to respond to risks (e.g. operational changes to manage peak energy loads).
- **Building in redundancy** or other features that increase the ability of infrastructure to withstand disruption and retain some functionality in the face of a hazard or shock (i.e. not catastrophically fail).
- **Improving physical resistance,** for example by using different materials or upgrading design or building standards.
- **Managing interdependency,** for example by allowing isolation of a critical part of the infrastructure or modular design.
- **Better enabling response and recovery,** to minimise short term impact and plan for long term impact.

It is important that each option identified addresses the underlying purpose of the infrastructure, i.e. whether it is natural hazard infrastructure.

Key steps

- Identify broad range of options that relate to the problems which the project is seeking to address.
- Consider the scope to adopt adaptive decision making when identifying options.

Outcome

- Do nothing, non-build solutions, build interventions and adaptive options which are responsive to the key natural hazard risks are considered during the options appraisal phase.

4 APPRAISING AND EVALUATING OPTIONS

Key points:

- Analysis of options should include quantification of the additional costs associated with the addressing natural hazard risks and the costs that are avoided by doing so. There is a range of methodologies which can be used to do this.
- Analysis should focus on the material impacts driven by natural hazards. This should include economic, environmental and social impacts. Effort spent on quantifying natural hazard risks should be proportional to materiality of the risks.

The [NSW Government Guide to Cost Benefit Analysis](#) (CBA) should be followed when appraising options. This section focuses on key considerations and techniques that can be applied to ensure that natural hazards are appropriately reflected in the analysis, consistent with the framework set out in the CBA guidelines.

4.1 Key options appraisal considerations

The purpose of a CBA is to directly compare the marginal costs and benefits of a range of potential investments. To guide decision-making, it is imperative that all material cost and benefits, including those related to natural hazards, are quantified in the CBA. This enables investment options to be directly compared, allowing the investments which provide the best value for money for the community to be identified. Where it is not possible to quantify costs or benefits, they should still be described qualitatively and included in the CBA to provide transparency for decision-makers.

There are several considerations when incorporating resilience impacts into the CBA:

- The **level of effort** spent on quantifying the impact of natural hazards in the CBA should be proportionate to size of the proposed investment and relevant natural hazard risks.
- The focus should be on **material impacts arising from natural hazards**, which should be incorporated into the CBA. This applies to both natural hazard infrastructure and other infrastructure.
- The **base case** should be carefully defined:
 - The base case is generally a 'business as usual' case which includes any resilience initiatives which would be progressed anyway, even in the absence of the investment under consideration.
 - The base case should identify the material natural hazard risks and the extent to which these are managed in the absence of the investment under consideration. For example, the extent to which flood risks are managed through existing assets and their design standards.⁵
 - The base case should incorporate climate change projections where relevant, specifically the NARClIM data set (see Appendix B for further details).

⁵ The options will then be assessed against incremental improvements.

- The base case should reflect the length of the operational life of the asset (which should also be the appraisal period for the CBA).⁶
- **Capture all costs and benefits related to natural hazard risks.** CBAs may include “avoided costs” (e.g. where a project option results in maintenance cost savings relative to the base case) as a benefit of an intervention. Interventions may also have negative impacts or externalities for the community (e.g. noise during or after construction), which should be captured in CBA.
- **Costs and benefits should be discounted** consistent with [NSW Treasury guidance](#). This incorporates sensitivity analysis of high and low discount rates to test the sensitivity of the stream of costs and benefits over time. Sensitivity analysis will be important where future risks involve substantial and irreversible intergenerational wealth transfers.
- **Distributional impacts** may be important in the consideration of resilience outcomes, for example flooding disruption may be more significant in lower socio-economic areas due to location and/or the lack of adaptive capacity of such communities. Consistent with NSW Treasury guidance. distributional analysis, which can be quantitative or qualitative, should be included in CBA.

4.2 Benefits and costs of resilience options

Identifying the costs and benefits of material impacts of natural hazards relative to the base case requires an understanding of:

- The nature of each option, and the resilient features included within that option, including an understanding of the specifications where the infrastructure would be made more resilient than the base case (e.g. design specifications).
- The means by which these features reduce risk or adapt to uncertainty, either by reducing in the likelihood of a natural hazard scenario and/or by mitigating the consequences when that scenario occurs.

The process for calculating natural hazard costs or benefits is the same for both natural hazard infrastructure and other infrastructure, and can be summarised as:

- **Estimating the likelihood** of the natural hazard risks for each option. This should build on the identification of relevant natural hazard risks discussed in Section 2.2, and take place for each option identified following the process set out in Section 3.2. This estimation should account for:
 - both a single point of failure or multiple points of failure e.g. flooding affecting a single on-ramp for a new road or flooding affecting multiple points along the route of the new road.
 - any changes in likelihood over time.
- **Identifying the consequences** of the natural hazard risks for each option, including for example the direct cost of the impact or failure of the asset and disruption to businesses and the community. Operators of assets are a useful source of information about the likely consequences of natural hazard risks.

⁶ It may be necessary to consult with the relevant experts, particularly Treasury, where a place-based infrastructure investment evaluation covers multiple assets with different lifespans

- **Calculating a monetary value relating to the consequences.** This may include, for example, the cost of repairing or replacing the asset or estimating the duration and financial severity of disruption to business and the community.

The quality of the evidence base will vary depending on the impact that is being quantified. Previous studies of similar investments can be a good source for information on the monetary consequences of natural hazards. The [Australian Transport and Assessment Planning](#) guidelines are another source. Agencies are encouraged to discuss with Treasury appropriate evidence to inform the CBA options appraisal. Where material impacts cannot be monetised, they should still be described qualitatively in the broader appraisal.

This process should be undertaken for each material natural hazard risk and input in the CBA for each option, along with other direct costs and benefits. It may be that for some options there may be no incremental impact (i.e. impact equal to zero) for a particular natural hazard, but it is important to establish a consistent CBA framework across all options.

4.3 Techniques for quantifying risk and uncertainty

4.3.1 Techniques within the CBA framework

Within a standard CBA framework resilient-related impacts can be valued using the following techniques (ordered from least to most complex):

- Where it is not possible to monetise the incremental change in a risk, or where the magnitude of the natural hazard risk is small, there are several mechanisms for considering resilience risks:
- **Sensitivity analysis** can provide information about how **changes in different variables** within a defined state of the world will affect net present value (NPV), as well as the distribution of the costs and benefits.
- Scenario analysis can be used to test how sensitive CBA estimates are to key uncertainties by characterising different states of the world (i.e. different scenarios).
- **Expected Net Present Value (ENPV)** can be used to value impacts associated with infrastructure's **ability to withstand shocks and stressors** by estimating the reduction in the risks associated with a resilience related action. This involves weighting the incremental cost or benefits associated with addressing a risk by the probability or likelihood of that risk eventuating. ENPV is essentially a formalisation of the general technique for calculating natural hazard costs or benefits presented in Section 4.2.
- **Real options analysis (ROA)** can be used to estimate the additional value associated with options that facilitate **adaptation** in the future by creating the flexibility to defer some decision making until a point in the future when there is likely to be more certainty. See **Box 5** for further details of this methodology.⁷

While the exact approach to managing risk and uncertainty will depend on the project in question, in general, the assessment of risk and uncertainty that is undertaken should be proportionate to the size of the project. For example, scenario analysis may take the form of asking simple 'what if' questions for small and medium sized projects with limited natural hazard risk. But it could extend to creating

⁷ Another useful source is the Victorian Department of Treasury and Finance's technical guide on real options analysis. Available at: <https://www.dtf.vic.gov.au/investment-lifecycle-and-high-value-high-risk-guidelines/technical-guides>

detailed models of possible future states of the world for major policies and projects that are large, complex or have significant interfaces with other infrastructure.

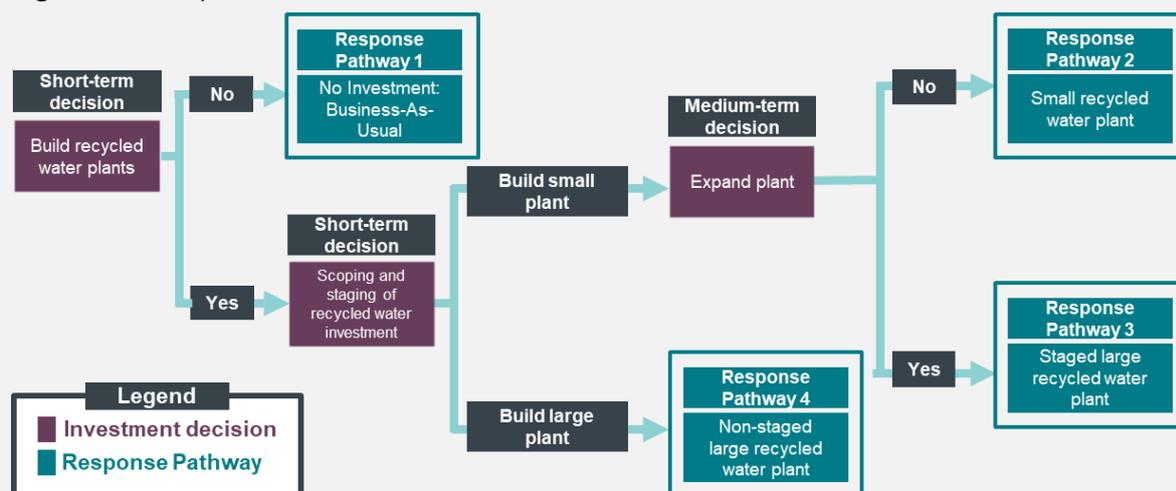
Box 5: Real Options Analysis

ROA is of most interest when considering options that enable adaptive management, including the flexibility to defer some investment decision making to a later stage. This is because this approach can be used to value the benefit of the flexibility associated with any adaptation or adaptive management that is enabled. The process for undertaking a ROA can be summarised as:

- **Identifying the key sources of future uncertainty**, for example the frequency and severity of extreme weather events.
- **Identifying response pathways to uncertainty**. A response pathway is composed of a series of investment decision points. Response pathways may include making a large investment today or making a small investment today and deferring the decision to make a further investment until the future (when there is greater certainty about a key variable such as exposures to a natural hazard).
- **Building a decision tree that maps the key uncertainties and response pathways to the uncertainty**, given the range of potential outcomes (see **Figure 2** for an example decision tree). This approach usually involves focusing on the most material decisions/responses to uncertainty, rather than attempt to incorporate every possible response.
- **Calculating the expected present value of each branch of the decision tree** by estimating the NPV of each scenario and the probability of the cash flows occurring.
- Identifying the strategy that maximises the expected value of the project by undertaking CBA at each potential outcome on the decision tree.

A simple, practical example of a real options decision tree is shown below in **Figure 2**.

Figure 2: Example decision tree for ROA



4.3.2 Supplementary decision-making techniques

The techniques in Section 4.3.1 rely on information about the likelihood and consequences of natural hazards, and the ability to estimate the impacts (or costs and benefits) arising from different responses to this exposure. Where insufficient evidence is available, there are several techniques that can supplement, but not substitute for, a CBA to inform the assessment of resilience.⁸

These supplementary decision-making techniques include:

- **Break-even analysis:** which focuses on establishing the magnitude of the benefits which would be required to justify the cost of an intervention. This requires some understanding of the drivers of benefits and the value of achieving certain outcomes. This analysis can then be considered alongside ‘benchmarks’ from previous projects to inform a judgement call as to whether the magnitude of benefits are realistic.
- **Robust decision making.** is a structured modelling approach to test adaption options or strategies. It applies where there is a high degree of uncertainty (e.g. climate change) where it is not possible to estimate probability or probability distribution. Options or strategies are assessed against a range of plausible future scenarios where the performance of each option or strategy is measured with metrics such as physical effectiveness or economic efficiency, to determine which options are likely to achieve on agreed outcomes. This is a relatively new technique being applied on some infrastructure projects in the United Kingdom.⁹

4.3.3 Summary of techniques for quantifying risk and uncertainty

Table 2 provides a summary of techniques within the CBA framework which can be used to deal with risk and uncertainty.

One additional technique which could be used in conjunction with the techniques presented in **Table 2** is Monte Carlo analysis. This involves using software that can run hundreds of scenarios based on a probability distribution of the uncertain variables. It can therefore be used to provide an insight into the distribution of possible outcomes. Further details in Monte Carlo analysis can be found in the [NSW Government Guide to CBA](#).

Table 2: Summary of techniques for quantifying risk and uncertainty

TECHNIQUE	DESCRIPTION	WHEN IS IT APPROPRIATE TO USE THIS TECHNIQUE?
Techniques that can be used within a CBA framework		

⁸ See Appendix 8 of the NSW Government Guide to Cost-Benefit Analysis, other economic appraisal methods can be useful supplements to, but not substitutes for, CBA in some cases.

⁹ Further details on this methodology can be found here: Lempert *et al.* (2003), Shaping the next one hundred years: new methods for quantitative, long-term policy analysis

TECHNIQUE	DESCRIPTION	WHEN IS IT APPROPRIATE TO USE THIS TECHNIQUE?
Sensitivity analysis	<ul style="list-style-type: none"> Provides information on the sensitivity of CBA to assumptions about key variables. At its simplest this could involve analysis of NPV assuming the worst and best cases for key assumptions, which requires relatively limited information, and can help identify when further analysis is required. 	<ul style="list-style-type: none"> Consistent with the NSW Government Guide to CBA, every CBA includes sensitivity analysis of key variables and assumptions. To manage the inherent uncertainty over future costs and benefits of project options, particularly for those parameters that may be material to the project evaluation. Ideally, there is information available about the probability distribution of risks in key variables.
Scenario analysis	<ul style="list-style-type: none"> Tests how sensitive estimates of NPV are to key uncertainties by describing different states of the world that might occur over the medium to long term. Scenarios consist of descriptions of the alternative future environments which differ in crucial respects, usually in terms of significant or 'big picture' factors. 	<ul style="list-style-type: none"> To improve the understanding of the way different states of the world, including for example different climate change scenarios, affect NPV. Best used in conjunction with sensitivity analysis, to explore the effect of uncertainty within a defined state of the world.
Expected NPV	<ul style="list-style-type: none"> Accounts for the likelihood of different outcomes occurring. Calculated by weighting each outcome by its estimated probability of occurring. 	<ul style="list-style-type: none"> Where there is uncertainty over particular outcomes occurring, and this information about this uncertainty is unlikely to improve over time.
Real options analysis	<ul style="list-style-type: none"> Incorporates options to allow flexibility to defer some decision making until the future (when it is likely to be uncertain). 	<ul style="list-style-type: none"> When information about uncertainty is likely to improve in the future. When there is flexibility to make investment decisions in stages, rather than an 'all or nothing' upfront commitment.
Supplementary decision-making techniques		
Break-even analysis	<ul style="list-style-type: none"> Profiles costs over time and uses this to identify the level of benefits required to provide a value for money solution. 	<ul style="list-style-type: none"> As a supplement to CBA when it is not possible to estimate the likely benefits of resilience.
Robust decision making	<ul style="list-style-type: none"> Quantitative approach which assesses the proposed initiatives across all plausible states of the world and identifies the initiative most robust across these. 	<ul style="list-style-type: none"> As a supplement to CBA when there is 'deep uncertainty' i.e. the level of uncertainty cannot be estimated.

4.4 Informed decision-making

The purpose of the analysis described in the proceeding sections is to inform the appraisal and evaluation of investment options (see **Box 6** for a practical example). This can then inform decision-making:

- The preferred option can be identified where the analysis shows that, for most of the plausible scenarios, a resilience intervention which responds to natural hazard risks will best deliver value for money.
- If the analysis demonstrates the resilience intervention is only likely to deliver the best value for money under extreme assumptions it is unlikely to be the preferred option.
- If the analysis shows the benefits are highly uncertain, and the NPV is highly sensitive to key assumptions, a good strategy may involve building in adaptive capacity now and revisiting key investment decisions at a later stage.

Box 6: Case Study – Flood risk in the Hawkesbury-Nepean Valley

The Hawkesbury-Nepean Valley in Western Sydney has the highest flood risk in NSW, if not Australia. The floodplain currently has 134,000 residents and workers, plus many pieces of infrastructure at risk. The risk is not limited to human life, property, and infrastructure damage caused by the impact of a flood alone – the ability of roads to accommodate an evacuation and inadequate planning for such eventualities also contribute to the risk. A regional, place-based approach to flood response was adopted, and it determined that both infrastructure and non-infrastructure options were necessary. As a number of possible solutions had previously been investigated for the Hawkesbury-Nepean Valley, a portfolio approach was used.¹⁰

A number of portfolios each containing different option combinations were developed. Importantly, an optimal portfolio must consider how all the options interact, and the cost of the whole portfolio of measures, not just each option alone. Some options may have a higher unit cost than others in the portfolio, but play an important role in achieving a cost-effective portfolio of benefits. The capacity of different options to reduce flood risk was quantified with the use of computer simulations and scenario testing to understand the relative benefits and cost of each under a range of different assumptions about future uncertainties, such as future growth and climate risk.

In the case of road upgrades to improve flood evacuations, it initially emerged that the flood risk mitigation option was not cost effective because it required upgrades outside regular renewal cycles. However, one outcome was that new policies and plans will now require additional resilience benefits of road upgrades to be considered for during routine road upgrade assessments (rather than only during a resilience-specific investment appraisal process). In effect, the timing of the investment decision was changed to ensure both that the upgrade was likely to be more cost effective, and that future decisions would consider resilience.

Source: Infrastructure NSW

¹⁰ A portfolio is a suite of infrastructure and non-infrastructure mitigation measures that are deployed in a planned sequence i.e., short (0-5 years), medium (6-15 years) and longer term.

Key steps

- The base case against which options are compared should include resilience considerations.
- Consideration should be given to the material impacts of natural hazards during options analysis and appraisal. These impacts should be identified and quantified.
- Consideration should be given to the most appropriate technique to analyse risk and uncertainty relating to material natural hazards.

Outcome

- Resilience forms part of the CBA analysis to inform the identification of an infrastructure investment option.

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5 EMBEDDING RESILIENCE IN MONITORING AND EVALUATION

Key points:

- Monitoring and evaluation should include consideration of updated information regarding risks and uncertainty identified in the asset operations and planning stage.
- Post implementation evaluations and Asset Management Plans are key documents at this stage.

The dynamic nature of natural hazards means it is important to monitor and evaluate operational infrastructure resilience periodically – and not to ‘set and forget’. Robust monitoring and evaluation should be applied to existing infrastructure, not just to planning for new infrastructure.

Monitoring and evaluation is important to ensure that:

- learning about past decisions is reflected in future investments, including maintenance and renewal and replacement requirements.
- accountability is taken by asset owners so investments are made in the options that deliver the best value for money.

Agencies will use Asset Management Plans (AMP) as their core tool to reassess risk and review mitigation strategies including investment decisions to replace, maintain and dispose of assets. As part of this process, new information will become available that may impact the profile of risk upon assets. Climate change projections are an example of this. **Box 7** presents a case study on Sydney Water’s approach to ongoing resilience assessment.

In addition, as per **business case guidelines**, a post-implementation evaluation should be completed for an infrastructure investment. From a resilience point of view, there are three key elements to this evaluation:

- **Updating the assessment of project specific resilience risks** and ascertaining whether circumstances have changed such that resilience-related investment requires further consideration.
- Undertake a **benefits realisation evaluation** with attention given to resilience benefits targeted. [NSW Government’s Benefits Realisation Management Framework](#) provides more details how best to do this.
- Seeking **learnings and evidence** related to resilience impacts which can be used to inform the asset owner for review in the AMP as well as future infrastructure planning.

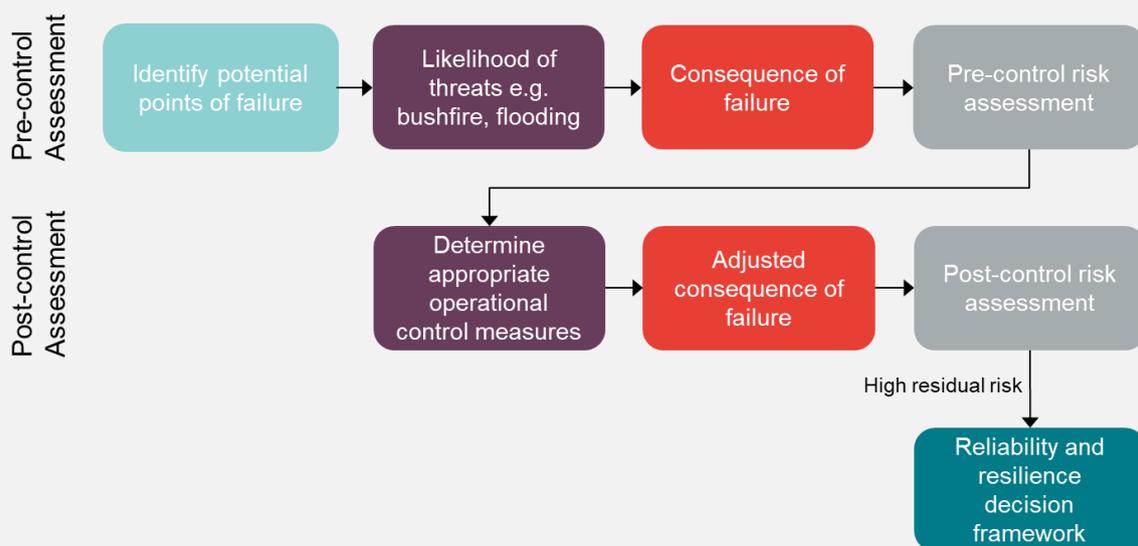
Box 7: Case Study – Sydney Water ongoing resilience assessment

Sydney Water carries out resilience assessments of its water and wastewater systems to determine potential vulnerabilities to risks including natural hazards. Future scenarios considered as part of this process include bushfire, flood and landslips.

The resilience assessment methodology (See **Figure 3**) begins with identification of single points of failure in each water network and treatment plant. Risk assessments are undertaken for each point of failure, using Sydney Water’s Risk Assessment Framework. The outcomes of the risk assessments are adopted for the Asset Management Plans and System Plans for each water and wastewater network and treatment plant.

The most recent example of the use of this tool was for the Cronulla wastewater system which considered climate change hazards including coastal inundation, bushfire, and heatwaves. The tool assists in quantifying climate change risks (financial and non-financial) for user-defined scenarios and forecasts asset risk costs over time due to climate change and extreme events to inform future infrastructure planning decisions.

Figure 3: Sydney Water Resilience Assessment Process



Key steps

- Establishing a process for ongoing monitoring and evaluation.
- Undertake a post implementation evaluation for infrastructure investments.

Outcome

- Continued consideration of resilience issues across the life of the infrastructure asset.

A INTERDEPENDENCIES IN INFRASTRUCTURE INVESTMENT

Infrastructure assets may influence or be dependent on one another, which can create either positive or negative resilience impacts. This can exacerbate risks and therefore interdependence needs careful consideration.

Interdependency occurs in a number of different ways, including for example:

- **physical** e.g. the dependency of a water treatment works on an electricity supply to power the facility.
- **information and digital** e.g. emergency service response for an evacuation from a tunnel being reliant on data on the physical layout of the tunnel.
- **geographic** (i.e. physical proximity) e.g. an airport being dependent on a highway link for accessibility for customers, workers and supplies.
- **organisational or governance** e.g. a public transport organisation being dependent on the actions of the roads authority when responding to a shock.

It is also important to consider the social and community intersection with these interdependencies, i.e. linkages between 'hard' infrastructure systems and the human social and community networks, structures, organisations, etc. with which they interface. The resilience of communities is impacted by the resilience of infrastructure.

The UK Treasury's supplement to the [Green Book "Valuing Infrastructure Spend"](#) includes further detail on valuing interdependence, such as how to identify instances of interdependence, potential options for managing interdependence and how to assess and value the associated impacts (see Chapter 3).

B RESOURCES

The following outlines useful resources and key contacts to assist with putting this guidance in to practice:

Cross-Dependency Initiative (XDI): Identifies risk resulting from interdependencies at the asset level. Helps agencies to better prepare for and respond to heatwaves, storms, floods, droughts and bushfire as well as improved information, resources and guidance at a local level on climate change impacts, risks and adaptation options.

adapt.nsw@environment.nsw.gov.au

Adapt NSW and the Office of Environment and Heritage: Expert advice on existing and climate change induced natural hazard risks to infrastructure construction, maintenance and operation.

info@environment.nsw.gov.au

Office of Emergency Management: Expert advice on Emergency management, and the NSW Government responses to natural disasters.

oem@justice.nsw.gov.au

Climate Change in Australia: The Australian Government's climate change projection. This includes 40 global climate models, specially managed around natural resource regions.

<https://www.climatechangeinaustralia.gov.au/en/climate-projections/>

The New South Wales and ACT Regional Climate Modelling (NARClIM): The NSW Government's climate change projections. Comprised of 12 a model ensemble, NARClIM provides climate projections for South East Australia at a 10km resolution.

<https://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW>

Common Planning Assumptions: The NSW Government's agreed information assets for use by agencies and others to prepare proposals, business plans and strategies which rely on projections. These contain the existing natural hazard datasets used the NSW Government, along with advice for using climate projections for infrastructure planning.

<https://www.transport.nsw.gov.au/data-and-research/common-planning-assumptions>

Centre for Evidence and Evaluation, NSW Treasury: For cost benefit analysis queries
costbenefitanalysis@treasury.nsw.gov.au

Financial Management Policy, NSW Treasury: For business case guidelines queries
finpol@treasury.nsw.gov.au