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Building utility resilience to climate shocks: *Lessons from global case studies*

UTS Institute for Sustainable Futures

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Executive Summary

This document presents the preparation and synthesis of ten global case studies that demonstrate how diverse actors are increasing resilience by adapting their assets to climate induced shocks. The case studies cover locations from almost all continents, and across several sectors (e.g. water, transport and electricity) and actors (e.g. companies, utilities, and government). It builds on the earlier WSAA publication "Towards resilience" that illustrated how the urban water industry is being impacted by climate change and extreme events, and the how the industry is responding.

The main objective of this document is to provide examples that will:

- Provide a learning opportunity for Australian and New Zealand water and wastewater service providers (water utilities).
- Provide an opportunity to consider alternative approaches for responding to climate shocks.
- Identify methods to make the business case for resilient infrastructure within water utilities and with the relevant state/territory regulatory bodies.

Table A lists the ten case studies and shows the fairly even spread across six enablers for resilience to climate shocks that were evident. For many of the cases, previous experience with climate induced disruptions was a key motivator for considering future climatic impacts on their operations and investment planning. Specific details of the case studies can be found in the Addendum to this report.

Table A: Enabling factors for resilience to climate change shocks identified in the case studies

Case studies	Enablers					
	Strong Leadership	Regulations	Economics	Engagement & expectations	Collaboration & Co-benefits	Knowledge & experience
1: Copenhagen Metro: Integrating climate adaptation	●	●		●	●	●
2: Brisbane Airport: The New Parallel Runway	●			●		●
3: SSEN UK: Flood mitigation of electricity substations		●	●		●	●
4: Santiago: Adapting to high turbidity in raw water		●	●	●		●
5: Cape Town: Stormwater management	●				●	●
6: Victoria: Healthy Homes Program	●		●			
7: New York City: Wastewater Resiliency Plan	●		●		●	●
8: Copenhagen: Cloudburst solutions			●		●	●
9: Northumbrian Water: Collaborative Flood Alleviation				●	●	
10: United Utilities: Improving Operational Response and Recovery		●	●			

The **recommendations** from this review are listed below and categorised under the six key enablers.

Table B: Recommendations listed against the six enablers

Enabler	Recommendations
Strong leadership ***Leadership from politicians and senior positions is key to drive a climate adaptation vision and make public funds available for the transition. It also drives implementation of strategies and***	1. Water utilities' senior management should, in collaboration with key stakeholders, drive the embedding of climate adaptation into the organisation's processes for proactive and cost-effective investment in resilience. 2. Advocate for city/state/national leadership to support climate adaptation within water utilities (leverage any climate shock event to

Enabler	Recommendations
addresses institutional capacity requirements.	highlight this need), for example, through city/regional/state climate adaptation strategies and funding support. 3. Leverage off or align with existing internal and external leadership initiatives (e.g. strategies) to gain funding approval for climate adaptation investigation, design and construction.
Regulation ***Enabling regulation to encourage and support climate adaptation explicitly or through collaboration between agencies.***	4. Advocate with state or federal government to implement state or national reporting requirements to help utilities implement long-term planning of climate adaptation. 5. Work together with your state/territory pricing regulator to agree on an approach to enable investment in climate change adaption activities. 6. Identify regulations that indirectly support water utilities' climate adaptation approach.
Economics ***An economic evaluation framework to represent the value in climate adaptation investment for customers, organisations, and regulators. The framework should include not just the costs and benefits of climate adaptation, but non-monetised social and environmental costs and benefits, as well as avoided costs/impacts from implementing resiliency measures.***	7. Incorporate the cost of climate adaptation into the cost of delivering an operationally reliable asset or agreed service levels; and strengthen funding requests by quantifying the risk and cost of "doing nothing" to adapt to climate shocks. 8. Determine the avoided costs of undertaking climate adaptation/building resilience into water utilities' assets, including costs associated with emergency responses, clean-up, asset repairs and replacement, customer compensation and potential reputational damage. 9. In collaboration with your state/territory pricing regulator, consider the different economic assessment approaches used in the case studies (e.g. Ofwat's Value Framework) to understand how best to represent the costs and benefits of addressing climate adaptation requirements, and gain customer support for any additional costs.
Engagement and expectations ***Community and stakeholder engagement is key for confirming the vision and to support the implementation of the strategy. Understanding expectations helps clarify drivers for organisational strategies and investment decisions.***	10. Ensure stakeholder engagement in the benefits of climate adaptation investment occurs as early as possible and includes a diverse range of stakeholders. 11. Understand customer/community expectations when determining the level of service and operational reliability that water utilities plan to maintain during climate shock events. Include key stakeholders in this process, for example, the state/territory pricing regulator and bulk water supply authority.
Collaboration and co-benefits ***Building partnerships and long-term, mutually beneficial relationships with a broad range of agencies, including the private sector, creates the collaboration and data sharing needed for projects to be aligned with the strategy and implemented in a coordinated fashion. This should be driven at both the state and city levels.***	12. Strengthen the coordination and collaboration between multiple actors with a stake in city-wide climate adaptation, to support effective and good value climate adaptation. 13. Consider working with key stakeholders to develop a sector-wide standard for climate resilient measures to enable a sound and consistent approach to funding approval and adaptation. Stakeholders could include for example: bulk water supply authorities, water/wastewater utilities, state/territory pricing and environmental regulators, and WSAA. 14. Consider developing international partnerships such as the Copenhagen and NYC collaboration. To get support from countries/organisations that are further along on the climate adaptation journey.
Knowledge and experiences ***Organisational knowledge and capacity to include alternative approaches and a recognition of using experiences of climate events as a trigger for adaptation action. It may be necessary to set up a dedicated team to implement the strategy and manage related projects, until climate adaptation is integrated into everyday practices and thinking.***	15. Consider where climate change knowledge (to understand risks, impacts, and appropriate measures) can be strengthened internally or through external support. 16. Consider the common steps undertaken to implement climate adaptation from the case studies and determine what might be applicable for water utilities (common steps in brief: 1. understanding climate risk; 2. determining acceptable levels of service; 3. resilience measures needed; and 4. when to implement measures). 17. Work with external organisations that have knowledge in climate change (e.g. BOM) to support water utilities with building a sound understanding of climate risks and predicted impacts for their assets and services.

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1 Introduction

Australian and New Zealand water and wastewater utilities (water utilities) need to incorporate the impacts of climate change (both from shifting trends and sudden shocks) on its assets to ensure a reliable and undisrupted service to its customers. The increase in frequency and severity of these impacts means that climate resilience needs to become a business-as-usual planning and management approach. Much of the focus in the water sector to date has been on water supply security and increases in rainfall independent supplies.

The purpose of this document is to provide water utilities with a better understanding of what climate related shock impacts are relevant to their assets, what resilience strategies should be deployed, and what arguments would be best for making the business case stack up by using regulatory and policy drivers, and/or demonstrating the broader triple-bottom-line benefits.

Information for review was gathered through the development of ten short case studies, which are included as an addendum to this report. The case studies investigated are diverse, covering a range of utilities (both water and non-water)[1], climatic shocks, adaptation responses, and system interdependencies. The case studies cover new builds, asset upgrades and retrofits.

Key learnings have been synthesised from the ten case studies, based on the six enablers described in Section 2. From these key learnings, a set of recommendations have been developed for consideration by water utilities, which focus on ways to better adapt to the changing climate (see Section 4).

[1] Note that this study only explored water utility examples from overseas, Australian water utility examples were excluded.

2 Analysis framework

The following six enablers were used in the case studies and this synthesis report to frame the key enablers and drivers that supported the implementation of resilient measures (based on the One Water Paradigm shift framework).

- **Leadership:** Leadership from politicians and senior positions is key to drive a climate adaptation vision and make funds available for the transition. It also drives implementation of strategies and addresses institutional capacity requirements.
- **Regulations:** Enabling regulation that encourage and support climate adaptation explicitly or through collaboration between agencies.
- **Economics**: An economic evaluation framework for representing the value in climate adaptation investment for customers, organisations, and regulators. The evaluation framework should include not just the costs and benefits of climate adaptation, but non-monetised social and environmental costs and benefits, as well as avoided costs/impacts from implementing resiliency measures.
- ***Engagement and expectations***: Community and stakeholder engagement is key for confirming the vision and to support the implementation of the strategy. Understanding expectations helps clarify drivers for organisational strategies and investment decisions.
- ***Collaboration and co-benefits***: Building partnerships and long-term, mutually beneficial relationships with a broad range of agencies, including the private sector, creates the collaboration and data sharing needed for projects to be aligned with the strategy and implemented in a coordinated fashion. This should be driven at both the state and city levels.
- **Knowledge and experience**: Organisational knowledge and capacity to include alternative approaches and a recognition of using experiences of climate events as a trigger for adaptation action. It may be necessary to set up a dedicated team to implement the strategy and manage related projects, until climate adaptation is integrated into everyday practices and thinking.

3 Case studies snapshot

As highlighted in Table 1, a range of actors were explored, from corporations to government agencies, local councils and utilities that were both privately and publicly owned (shown in blue text). Many of the case studies adapting to climate shocks covered the project stages of planning and implementation. While other case studies covered top-down strategies. An operational response and pilot study were also included.

With regards to the resilience outcomes achieved by the case studies, many of the case studies adopted a robust approach to dealing with climate impacts, by building more resilient infrastructure. Only two case studies implemented measures that provided flexibility in their operations to deal with climate induced impacts on their service delivery, while half considered measures to deal with disruptions to their service delivery through rapid operational responses and preparedness.

The focus was on finding a variety of climate shocks that were relevant to the Australian and New Zealand context (such as flooding, storm surges, bushfires and extreme heat); however; suitable published case studies could only be found which focused impacts due to flooding/extreme rainfall and storm surge/inundation. Many of the case studies were in response to a past extreme weather event(s), and were most often flooding or flooding-related because the clean-up effort and operational response required after a flood-type event is often considerable, and infrastructure also needs to be repaired and replaced. This is expensive and time-consuming; and can lead to communities having disrupted water and/or wastewater services for an extended period of time. These types of experiences motivate climate adaptation action and make it easy to justify the expenditure of large projects/programmes to prevent the recurrence of such damage in the future.

Table 1: Case studies snapshot and resilience outcomes

Case study names	Case Study actors	Sector	Shocks	Resilience Outcomes		
				Robustness	Flexibility	Preparedness
1: Copenhagen Metro: Integrating climate adaptation	Metroselskabet (The Metro Company)	Transport	Storm surge Flooding	✓		✓
2: Brisbane Airport: The New Parallel Runway	Brisbane Airport Corporation	Transport	Storm surge Flooding	✓		✓
3: SSEN UK: Flood mitigation of electricity substations	Scottish & Southern Electricity Networks (SSEN)	Electricity	Flooding	✓		✓
4: Santiago: Adapting to high turbidity	Aguas Andinas (Andean Waters)	Water	Flooding		✓	
5: Cape Town: Stormwater management	City of Cape Town	Stormwater	Storm surge Flooding	✓		
6: Victoria: Healthy Homes Program	Victorian Government	Housing	Extreme temperatures	✓		
7: New York City: Wastewater Resiliency Plan	New York City Department of Environmental Protection	Wastewater	Storm surge Flooding	✓		✓
8: Copenhagen: Cloudburst solutions	City of Copenhagen	Stormwater	Flooding	✓		
9: Northumbrian Water: Collaborative Flood Alleviation	Northumbrian Water, Environment Agency & Newcastle City Council	Water	Flooding	✓		
10: United Utilities: Improving Operational Response and Recovery	United Utilities	Water	Storm surge Flooding		✓	✓

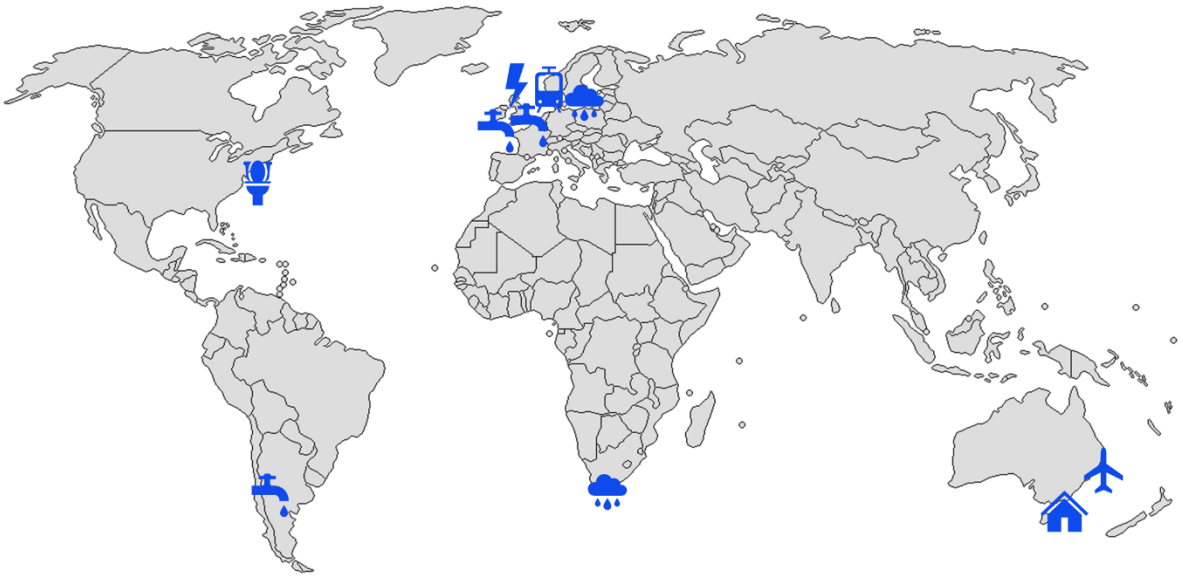

Figure 1: Geographical location of case study sectors

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4 Key learnings

Enablers of the case studies

Table 2 summarises the enabling factors for resilience to climate shocks that were evident in the ten case studies. There was a fairly even spread of the six enablers across the case studies, with stronger emphasis on economics, collaboration & co-benefits, and knowledge & experience. For many of the cases, previous experience with climate induced disruptions was a key motivator for considering future climatic impacts in their operations and investment planning.

Table 2: Enablers for resilience to climate change shocks identified in the case studies

Case studies	Enablers					
	Strong leadership	Regulations	Economics	Engagement & expectations	Collaboration & co-benefits	Knowledge & experience
1: Copenhagen Metro: Integrating climate adaptation	●	●		●	●	●
2: Brisbane Airport: The New Parallel Runway	●			●		●
3: SSEN UK: Flood mitigation of electricity substations		●	●		●	●
4: Santiago: Adapting to high turbidity in raw water		●	●	●		●
5: Cape Town: Stormwater management	●				●	●
6: Victoria: Healthy Homes Program	●		●			
7: New York City: Wastewater Resiliency Plan	●		●		●	●
8: Copenhagen: Cloudburst solutions			●		●	●
9: Northumbrian Water: Collaborative Flood Alleviation				●	●	
10: United Utilities: Improving Operational Response and Recovery		●	●			
Totals	5	4	6	4	6	7

The salient aspects of each enabler, as found in the case studies, have been synthesised and are discussed below. A collation of the transferrable actions identified from the ten case studies is also provided in Appendix 1. The synthesised enablers and collated transferable actions have been used to develop high level recommendations listed under each of the six enabler sections below.

4.1 Strong leadership

Leadership directly enabled half of the case studies and was demonstrated by senior positions within organisations and by local and state government.

The cases that showed senior management leadership within the organisation were Copenhagen Metro and Brisbane Airport (Case Study (CS) 1 & 2), where climate change adaptation was integrated into the planning process and resulted in assets built to be operationally reliable during climate shock events such as flooding and heavy rainfall. In both cases, a risk-based approach was used to determine and mitigate against climate shocks.

Brisbane Airport (CS 2) also showed effective leadership in the management of their external contract for delivery of the project, with a focus on building a positive team culture and having incentives for going beyond the contract.

Leadership from higher levels of public governance, such as state and local government, enabled three case studies. Copenhagen Metro and New York City (CS 1 & 7) benefited from city-wide adaptation plans developed by local government and Victoria Healthy Homes (CS 6) benefited from state government support in climate adaptation investment. Importantly, the development of city-wide adaptive plans by government

was in response to experiencing a severe climate shock event. For example, after Hurricane Sandy in New York City, local government provided a comprehensive strategic response with large amounts of associated funding; enabling the NYC utility to develop a program of works to build resilience into all wastewater treatment plants and the majority of sewer pump stations.

A key leadership attribute for all five case studies included having clear strategies, policies and/or plans for responding to climate change in place at the corporate executive level to drive adaptation integration in planning and delivery of infrastructure. Clear strategies often enabled expenditure on climate adaptation - from climate modelling. The project design to construction. For example, Brisbane Airport (CS 2) invested in climate and flood modelling, and the design and construction of stormwater drainage, an elevated runway and a sea wall – were all demonstrated as necessary climate adaptation measures to ensure operational reliability.

The case of Cape Town Stormwater (CS 5) shows that even with good organisational knowledge and strong divisional leadership, there is still the risk that without quality communication and engagement between key stakeholders (in this case senior council leadership and elected council-representatives), it is difficult to successfully embed and sustain climate change strategies.

Recommendations:

1. Water utilities' senior management should, in collaboration with key stakeholders, drive the embedding of climate adaptation into the utility's processes for proactive and cost-effective investment in resilience.
2. Advocate for city/state/national leadership to support climate adaptation within water utilities (leverage any climate shock event to highlight this need), for example, through city/regional/state climate adaptation strategies and funding support.
3. Leverage off or align with existing internal and external leadership initiatives (e.g. strategies) to gain funding approval for climate adaptation investigation, design and construction.

4.2 Regulations

Four case studies included regulations as an enabler, although there was no case where regulation was the primary enabler in the climate adaptation decision. Only in UK (CS 3) did pricing regulation explicitly require climate adaptation, however the real trigger for this enabling regulation was experiencing a significant climate shock event and the collaborative effort of key stakeholders (including the regulator) to build resilience against future events. All other case studies, either found additional support or incentives through national legislation (CS 1, 3 & 10) or where there was a similar pricing regulatory environment as that for Australian and New Zealand utilities, they leveraged off their existing pricing regulation (CS 4 & 10) to enable expenditure in activities that improved climate resilience. Other enabling factors, either leadership, collaboration, or knowledge and experience were primary enablers for climate adaptation in these case studies. This is discussed in more detail below.

Case Studies 1, 3 & 10 demonstrated that climate resilience can be incentivised or regulated from the national level2. In UK for example, the energy industry regulator mandated a national approach to improving flood resilience of substations to an agreed standard, this provided SSEN (CS 3) with a clear justification and process for flood mitigation activities. The UK Climate Act requires essential service providers (CS 3, 9 and 10) to regularly report on what activities are being undertaken by them to adapt to climate change, which forces these utilities to consider climate change impacts in their planning. This requirement has helped to drive SSEN's climate adaptation responses and has supported United Utilities in long term climate adaptation planning, with United Utilities' first long-term plan to be released in 2022. In addition, Ofwat's Outcome Delivery Incentive requires utilities to report on the interruption to supply (or customer minutes lost), which further incentivises resilience since a disruption in services results in cash penalties.

[2] which depending on jurisdiction may be equivalent to the state level in Australia

In Denmark for example, the national parliament passed an Act to support expansion of Copenhagen's metro and set out the funding framework of this large construction project. Further, funding opportunities from the European Union for transport-related infrastructure projects in EU countries such as Denmark is only available to those that are resilient to the possible impact of climate change.

There are also cases where organisations utilised less direct legislation to support climate adaptation. For example, the Flood Risk Regulation 2009, requires the UK Environment Agency to prepare and publish flood risk information, including maps and management plans, on a six-year cycle. This is useful data for UK utilities like Northumbrian Water to support the assessment of their flood risk and provides a consistent national approach.

Aguas Andinas and United Utilities (CS 4 & 10) used their pricing regulator's existing determination process to get funding approved that inherently supported climate adaptation. Aguas Andinas received approval to construct standby raw water storage, while United Utilities was funded (and incentivised) to improve operational response and recovery, which has also helped to reduce the impacts of climate shock events.

Recommendations:

4. Advocate with state or federal government to implement state or national reporting requirements to help utilities implement long-term planning of climate adaptation.
5. Work together with your state/territory pricing regulator to agree on an approach to enable investment in climate change adaption activities.
6. Identify regulations that indirectly support water utilities' climate adaptation approach.

4.3 Economics

Six case studies used an economic evaluation framework to justify the worth of climate adaptation. Several economic assessment methods were used with various drivers, including:

- The city/state-wide adaptation case studies (CS 6, 7 & 8) incorporated financial, environmental and social considerations to provide a holistic perspective on costs and benefits.
- SSEN (CS 3) was driven by meeting national industry standards for flooding resilience.
- Aguas Andinas focused on what financial cost was acceptable to add to customer's bills to achieve improved resilience
- United Utilities (CS 10) were incentivised to avoid financial penalties from the pricing regulator, and also use customer engagement to place a dollar value on an uninterrupted service.

For Case Studies 3, 4 & 8, based on an assessment of the broader economic benefits to the community or customers, passing on the investment and operational costs to the customers was justified and usually accepted by the customers.

A Triple Bottom Line (TBL) economic analysis (considers financial, social and environmental consequences) was used to enable investment in the city-wide adaptation approaches in New York and Copenhagen (CS 7 and 8). TBL is generally considered a transparent and holistic approach to presenting the economic costs and benefits. In these two cases, the associated avoided costs of implementing climate adaptation were also determined, which strengthened the case for climate adaptation as the cost of no or inadequate adaptation was much higher than the cost of adaptation.

The setting of industry standards and minimum levels of service has meant that in some sectors, the inclusion of climate shock resilience (such as flooding in many of the examples) has been enabled through the traditional business case process and/or pricing determinations, and importantly the funding of these climate adaption measures was expected by the pricing regulator, and therefore supported (as with CS 3, 8 & 10).

Further with United Utilities (CS 10), the pricing regulator Ofwat requires United Utilities to engage with the customer to determine the value of investing in service improvements. This "value framework" approach provides a clear method for business case development and therefore funding approval during Ofwat's

pricing reviews. It is also worth noting that United Utilities is in the process of shifting economic assessment approach from the cheapest whole life cost model to a best value assessment model.

Victorian Healthy Homes (CS 6) demonstrated a novel approach to justify the investment by using the cost consequences analysis method to assess a range of costs and benefits, without aggregating them to a single score or set of indicators, as would be the case with TBL or multi-criteria analysis. This allowed the outcomes to be assessed individually on their own merit, without needing to monetise them.

Recommendations:

7. Incorporate the cost of climate adaptation into the cost of delivering an operationally reliable asset or agreed service levels; and strengthen funding requests by quantifying the risk and cost of "doing nothing" to adapt to climate shocks.
8. Determine the avoided costs of undertaking climate adaptation/building resilience into water utilities' assets, including costs associated with emergency responses, clean-up, asset repairs and replacement, customer compensation and potential reputational damage.
9. In collaboration with your state/territory pricing regulator, consider the different economic assessment approaches used in the case studies (e.g. Ofwat's Value Framework) to understand how best to represent the costs and benefits of addressing climate adaptation requirements, and gain customer support for any additional costs.

4.4 Engagement and expectations

Stakeholder engagement with a range of stakeholders, including local community environment groups, scientific organisations and traditional owners was demonstrated as key success factor for Brisbane Airport and Northumbrian Water (CS 2 & 9), especially as they involved large financial investments. Communicating the vision of the project, as it relates to improved levels of service and other ancillary social and environmental benefits, as broadly and early as possible helped to gain community support in these cases.

The private sector organisations for Case Studies 1, 3 and 4 also considered customer/stakeholder expectations and impacts if their service levels were not maintained during a climate shock event. SSEN (CS 3) saw prevention of substation flooding as saving not only costs of asset repair and customer compensation but understood that maintaining service levels prevented large costs to the community from lengthy and widespread power outages. Copenhagen metro (CS 1) took broader societal impacts of a reduced or closed metro service into consideration, noting that it would not only impact society, but cause reputational damage and affect meeting Metroselskabet's operation reliability target of 98%. Aguas Andinas (CS 4), who are dependent on renewal of contracts and concessions also considered the reputational damage on their business if they failed to respond to turbidity events impacting the treatability of their raw source water.

Recommendations:

10. Ensure stakeholder engagement in the benefits of climate adaptation investment occurs as early as possible and includes a diverse range of stakeholders.
11. Understand customer/community expectations when determining the level of service and operational reliability that the water utility plans to maintain during climate shock events. Include key stakeholders in this process, for example, the state/territory pricing regulator and bulk water supply authority.

4.5 Collaboration and co-benefits

The majority of case studies demonstrated the benefits of stakeholder collaboration with a view of sharing knowledge and experience and/or sharing the costs and benefits. Stakeholder collaboration took place across sectors (often involving service utilities and city planners) and across levels of government such as council and state departments.

Although a collaborative process takes time, the outcomes in these case studies have proven the benefits of having multiple parties working towards the same goal of resilience building, often helped by parties having complimentary knowledge, authority, and funding pools. For example in the UK, there was collaboration

between a water utility, council and environmental agency (CS 9) to mitigate local flooding and in the energy sector (CS 3); industry, government and regulators worked together to develop a national standard for flood resilience of substations.

Collaboratively setting design guidelines and zoning regulations for urban greening and infrastructure projects that promote resilience resulted in all parties working towards the same goal with fewer challenges and barriers (CS 1 and 7). For example, in Denmark, the collaboration and sharing of costs across agencies to deal with a common hazard (that of increasing flooding events) provided multiple benefits for all (CS 8).

An integrated co-benefit and cost sharing approach through partnerships with different levels of government and utilities was shown to be effective in implementing water sensitive approaches to flood risk management within the UK (CS 9). This case also shows that adapting to climate change can have multiple objectives, including – improving liveability by bringing water into the urban environment and creating habitat for wildlife and spaces for residents to enjoy.

Collaboratively developing industry standards that incorporate climate induced impacts into planning ensured that all parties were involved and onboard with any structural controls or engineering standard put in place (Case Studies 3, 5 & 7).

From the literature, it was also evident that across some of the case studies there was collaboration and sharing of knowledge, for example the two Copenhagen examples had mutual benefits from the cloudburst approach (CS 1 & 8). There was even collaboration across international jurisdictions between New York City and Copenhagen City (CS 7 & 8) which helped to build knowledge and strengthen resilience efforts against city-based flooding. These examples demonstrate the cross-boundary benefits of knowledge sharing for resilient outcomes.

Recommendations:

12. Strengthen the coordination and collaboration between multiple actors with a stake in city-wide climate adaptation, to support effective and good value climate adaptation.
13. Consider working with key stakeholders to develop a sector-wide standard for climate resilient measures to enable a sound and consistent approach to funding approval and adaptation. Stakeholders could include for example: bulk water supply authorities, water/wastewater utilities, state/territory pricing and environmental regulators, and WSAA.
14. Consider developing international partnerships such as the Copenhagen and NYC collaboration. To get support from countries/organisations that are further along on the climate adaptation journey.

4.6 Knowledge and Experience

Having sound climate change knowledge within an organisation that covers both the understanding of the impacts and the possible response measures is key to progressing the shift from BAU processes to ones that incorporate climate change responses. The case studies that demonstrated this enabler had the following attributes:

- Acceptance of the climate science as a valid input into the planning assumptions.
- Cultural alignment throughout the organisations on the approach for addressing climate risks from the board, senior management, through to the project teams.
- A process for understanding climate impacts at the asset level, to then inform the climate adaptation response.
- Collaboration with experts from the private sector and research institutions that enhanced the internal capability of many of the institutions leading the adaptation initiatives. This was shown to be beneficial for both the problem definition and planning stages.
- Embedding a continual review and reflection of the performance of infrastructure in terms of resilience to climate shocks.

The case studies also showed four common steps for implementing climate adaptation within the organisation, which are summarised below:

1. **Understanding climate risk to determine design standards** – climate modelling to understand the climate risk was commonly used to answer this question (Case Studies 1, 2, 3, 5, 7, and 8). This required specialised external input, for example, NYC (CS 7) utilised information from NPCC, and UK and Denmark relied on their metrological organisations (CS 1, 3 & 8). Operational experience from existing assets, as well as from emergency response and recovery also contributed (CS 2 & 7).
2. **Determine acceptable level of service** during a climate shock, with a range of inputs used to determine this, including for example: organisational objectives, customer expectations, cost to community, regulated requirements, climate risks, asset criticality, environmental impacts, etc. As was the case with Aguas Andinas, Brisbane Airport, and Copenhagen metro (CS 1, 2 and 4), the level of service was aimed at continuous service. With United Utilities, SSEN, and New York City (CS 3, 7 & 10) the level of service underwent a prioritisation process.
3. **What resilience measures** are needed to meet the agreed levels of service, for example, high climate shock resilience (and cost) through infrastructure upgrades like raising some/all infrastructure as with Brisbane Airport, and Copenhagen (CS 1, 2, 8); and in some cases with New York City and SSEN (CS 3, 7); or operational responses (and lowest cost) as in the case of United Utilities (CS 10) and in some cases with New York City (CS 7) where emergency sandbagging was the adopted mitigation measure.
4. **When to implement** resilience measures. In cases where the projects were new builds, these were integrated into the typical capital approvals and prioritisation processes (CS 2, 4 & 9); where an upgrade or modification was required to the asset, this needed to align with planned asset upgrades and funding availability, as was the case for SSEN and New York City (CS 3 & 7).

A specific knowledge barrier was highlighted in Cape Town (CS 5) around the long lead in times which resulted in a loss of knowledge and lack of continuity within the planning team, and secondly the disjuncture between the knowledge of the climate change impacts as understood by the planners versus that of the decision makers. It is the elected officials that approve funding for investments, and where this includes a resilience component, the funding can sometimes be denied or redirected to more immediate concerns.

Experiencing a climate shock event(s), became a significant enabler for climate adaptation in four of the case studies (CS 3, 4, 7 & 8). For example, A key enabler of the NYC Wastewater Resiliency Plan was Hurricane Sandy, which came about after the hurricane caused major damage to the city's WWTPs and sewer pump stations and pollution of the harbour from sewer overflows.

Recommendations:

15. Consider where climate change knowledge (to understand risks, impacts, and appropriate measures) can be strengthened internally or through external support.
16. Consider the four common steps undertaken to implement climate adaptation to climate shocks from the case studies and determine what might be applicable for water utilities (common steps in brief: 1. understanding climate risk; 2. determining acceptable levels of service; 3. resilience measures needed; and 4. when to implement measures).
17. Work with external organisations that have knowledge in climate change (e.g. BOM) to support water utilities with building a sound understanding of climate risks and predicted impacts for their assets and services.

5 Conclusion

The preparation and synthesis of the 10 case studies has provided an opportunity for Australian and New Zealand utilities to learn from other organisations across the world and be inspired by examples of successful climate change adaptation. The six enablers framework has supported the development of 17 recommendations that aim to support water utilities in better adapting their operations and assets to climate shocks.

Table 3: Recommendations listed against the six enablers

Enabler	Recommendations
Strong leadership	1. Water utilities' senior management should, in collaboration with key stakeholders, drive the embedding of climate adaptation into the organisation's processes for proactive and cost-effective investment in resilience. 2. Advocate for city/state/national leadership to support climate adaptation within water utilities (leverage any climate shock event to highlight this need), for example, through city/regional/state climate adaptation strategies and funding support. 3. Leverage off or align with existing internal and external leadership initiatives (e.g. strategies) to gain funding approval for climate adaptation investigation, design and construction.
Regulation	4. Advocate with state or federal government to implement state or national reporting requirements to help utilities implement long-term planning of climate adaptation. 5. Work together with your state/territory pricing regulator to agree on an approach to enable investment in climate change adaption activities. 6. Identify regulations that indirectly support water utilities' climate adaptation approach.
Economics	7. Incorporate the cost of climate adaptation into the cost of delivering an operationally reliable asset or agreed service levels; and strengthen funding requests by quantifying the risk and cost of "doing nothing" to adapt to climate shocks. 8. Determine the avoided costs of undertaking climate adaptation/building resilience into water utilities' assets, including costs associated with emergency responses, clean-up, asset repairs and replacement, customer compensation and potential reputational damage. 9. In collaboration with your state/territory pricing regulator, consider the different economic assessment approaches used in the case studies (e.g. Ofwat's Value Framework) to understand how best to represent the costs and benefits of addressing climate adaptation requirements, and gain customer support for any additional costs.
Engagement and expectations	10. Ensure stakeholder engagement in the benefits of climate adaptation investment occurs as early as possible and includes a diverse range of stakeholders. 11. Understand customer/community expectations when determining the level of service and operational reliability that the water utility plans to maintain during climate shock events. Include key stakeholders in this process, for example, the state/territory pricing regulator and bulk water supply authority.
Collaboration and co-benefits	12. Strengthen the coordination and collaboration between multiple actors with a stake in city-wide climate adaptation, to support effective and good value climate adaptation. 13. Consider working with key stakeholders to develop a sector-wide standard for climate resilient measures to enable a sound and consistent approach to funding approval and adaptation. Stakeholders could include for example: bulk water supply authorities, water/wastewater utilities, state/territory pricing and environmental regulators, and WSAA. 14. Consider developing international partnerships such as the Copenhagen and NYC collaboration. To get support from countries/organisations that are further along on the climate adaptation journey.
Knowledge and experiences	15. Consider where climate change knowledge (to understand risks, impacts, and appropriate measures) can be strengthened internally or through external support. 16. Consider the common steps undertaken to implement climate adaptation from the case studies and determine what might be applicable for water utilities. 17. Work with external organisations that have knowledge in climate change (e.g. BOM) to support water utilities with building a sound understanding of climate risks and predicted impacts for their assets and services.

Appendix 1 Transferable actions from case studies

A collation of the transferrable actions identified from the ten case studies is provided in Table 4 below. These transferable actions have been drawn from the enabling factors identified in each case study, and also provide more detail to the recommendations provided in the Key Learnings section.

Table 4: Collation of final transferable actions from the case studies

Case studies	Strong Leadership	Regulations	Economics	Engagement & expectations	Collaboration & Co-benefits	Knowledge & experience
1: Copenhagen Metro: Integrating climate adaptation	Embed climate adaptation into water utilities' internal infrastructure delivery and asset management approaches. Ensuring integration of climate risk identification and adaptation within the business rather than regarding it as an optional or a separate stream of activity. (C)			Determine the level of service that water and wastewater customers expect during a climate shock event, to support climate adaptation decision making. (C)	Identify where to influence climate adaptation measures that impact a greater geographic area (e.g. precinct, town, or city) and reduce the climate adaptation requirements the water utility needs to undertake on their assets (rather than only protecting the utility's assets in isolation). This will require working with government and key partners. (C&I)	Improve the levels of climate change risk knowledge within water utilities. (C)
2: Brisbane Airport: The New Parallel Runway	Long term view of project requirements for addressing climate shocks is considered in strategies and from project identification to delivery. (C) Consider a team-focused approach for contractors and consultants engaged by water utilities to deliver climate adaptation, including incentives for those who go beyond the contract. (C)		Incorporating the cost of climate adaptation into the cost of delivering an operationally reliable asset versus the risk and cost of failure. (C) Consider climate shocks as a project risk to be mitigated for the life of the asset through the business case process. (C)	Engage with local stakeholders (e.g. local community groups) for support in improved understanding and management of climate shocks. (C)		Build organisational knowledge by talking with the O&M teams to understand what was is working well or not working at existing assets. (C)
3: SSEN UK: Flood mitigation of electricity substations		Consider jointly examining the current assessment of impacts and adaption options			Consider advocating for a sector-wide approach to assessing and designing resilience measures for	

Case studies	Strong Leadership	Regulations	Economics	Engagement & expectations	Collaboration & Co-benefits	Knowledge & experience
		with the relevant state/territory pricing regulator, with the aim of agreeing a way forward that will be considered as part of the next round of pricing review, to overcome net present value issues when developing a business case. (C&I)			climate shocks, with key industry, government, and regulatory stakeholders' part of a "task force", possibly with WSAA. (I) Ensure any standards developed make allowances for climate change to handle uncertainty about future risk, and keep standards under review, updating to take account of new information. (I)	
4: Santiago: Adapting to high turbidity in raw water		Demonstrate to the regulator that investment is needed to maintain a reliable supply to customers; and avoid frequent restrictions due to intermittent high turbidity. This will require collaboration with any associated bulk water supply authority or similar. (C & I)		Survey customers to establish the level of service expected during increased cases of turbidity. (C & I)		Plan and implement infrastructure investments to avoid disruptions to water services, and ensure water security 24/7 based on climate science and projected rates of soil erosion (or flooding) in raw water (C)
5: Cape Town: Stormwater management	Ensure climate adaptation policy positions are developed first, to give support to people within the organisation with the knowledge and motivation to deliver on climate adaptation. (C) Combining the technical expertise required to deal with the complex and evolving knowledge base with the political (and economic) expertise to				Strengthening the coordination and collaboration between multiple actors with a stake in city-wide climate adaptation. (I)	

Case studies	Strong Leadership	Regulations	Economics	Engagement & expectations	Collaboration & Co-benefits	Knowledge & experience
	address contested trade-offs and value-based judgements that underpin these decisions. (C & I)					
6: Victoria: Healthy Homes Program			Consider using the Cost Consequence Analysis approach for assessing the costs and benefits of an intervention, and avoid monetising the outcomes, assigning weights to the indicators and/or summing the scores using MCA. This approach could be especially useful for assessing outcomes associated with investments aimed at delivering liveability objectives, such as local cooling and green open space. (C & I) Consider multiple benefits from adaptation responses e.g. community benefits as well as SW infrastructure resilience. (C)			
7: New York City: Wastewater Resiliency Plan	Proactively undertake resiliency and adaptation planning so risks from climate shocks are understood and there is an agreed approach of how to balance risk and resiliency adaptation needs for capital projects. (C)		Consider a Triple Bottom Line Analysis (financial, social and environmental) to infrastructure risk analysis (Module two) to guide adaptation selection and prioritisation (and compare against “do nothing” costs of repairs and disaster relief). (C&I)		Undertake strategic planning to envision resilient participatory approaches that bring together key stakeholders to agree on common goals for the future. (C)	Refine emergency response plans to improve disaster preparedness and recovery based on risk assessment and feedback from operating staff. (C) Revise engineering design standards to accommodate anticipated increases in sea level and storm surges. (C&I) Develop climate adaptation plans for areas at-risk to climate shocks, with ready-to-implement

Case studies	Strong Leadership	Regulations	Economics	Engagement & expectations	Collaboration & Co-benefits	Knowledge & experience
						projects that can be either incorporated into planned asset upgrades/renewals or actioned when funding opportunities become available (e.g. after a climate shock event). (C)
8: Copenhagen: Cloudburst solutions			A cost-benefits analysis that included socio-economic outcomes can provide a compelling justification for implementing adaptation measures that benefits a wide sector of the community. (C & I)		Building partnerships between local governments and utilities to share the costs and benefits of implementing a program of adaptation actions. (C)	
9: Northumbrian Water: Collaborative Flood Alleviation				Consider WSUD solutions to flood risk mitigation that also provide additional benefits for the local community and ecology. (C&I)	Look for opportunities where a project that isn't viable as a single-stakeholder project, would benefit from a collaborative/partnership approach with multiple stakeholders combining their skills, powers, and funding allocations to justify a project proceeding, and deliver worthwhile outcomes for customers. (I)	
10: United Utilities: Improving Operational Response and Recovery			Explore United Utilities and Ofwat's "value framework" approach to business case economic assessments. Engage with the relevant state/territory pricing regulator on any associated regulatory reform. (I&C)			In climate risk assessments, consider appropriateness of response and recovery as a form of climate adaptation (considering potential cost of failure and impact to customers (C)

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