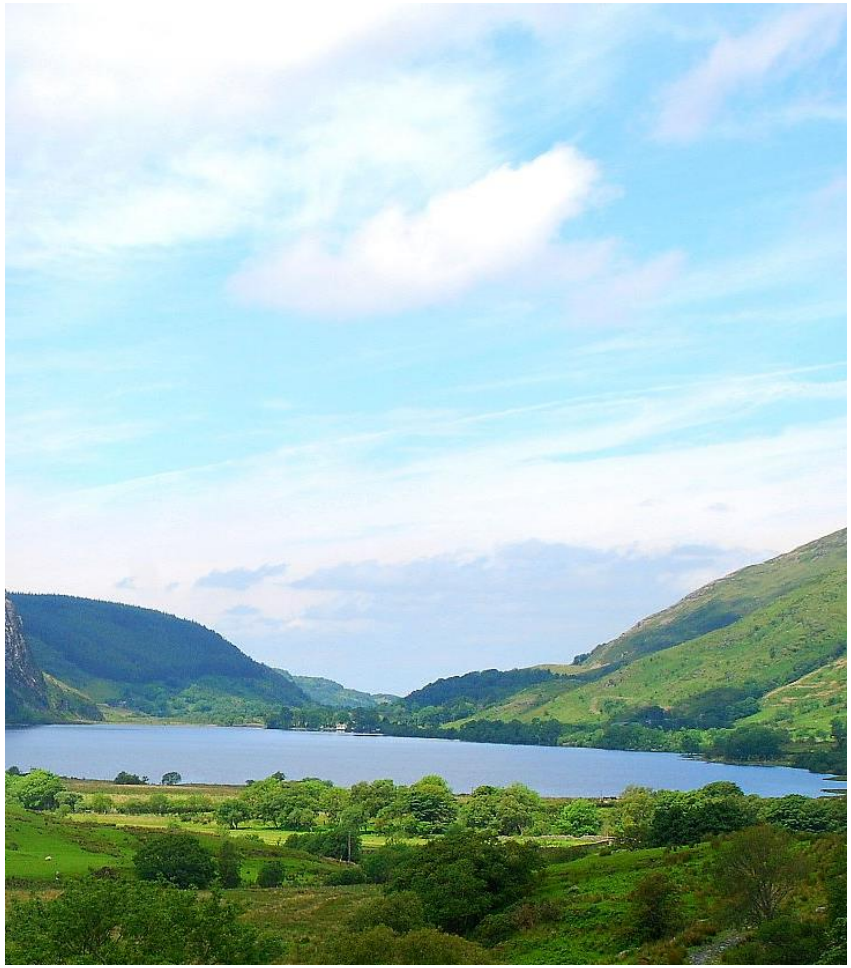
Welsh Water Resilient Systems Approach

Issue

6 August 2019

Contents



1. Introduction

In 2018, Welsh Water submitted its PR19 business plan to Ofwat for regulatory review. On the topic of resilience, Ofwat requested the following action:

"*The company should provide a commitment that it will, by 22 August 2019, prepare and provide to us an action plan to develop and implement a systems based approach to resilience in the round and ensure that the company can demonstrate in the future an integrated resilience framework that underpins the company's operations and future plans showing a line of sight between risks to resilience, planned mitigations, package of outcomes and corporate governance framework.*"

Welsh Water is now in the process of preparing the plan for how it will develop and implement a systems-based approach to resilience in the round. Welsh Water's Resilient Systems Approach (RSA) will provide an approach to identify and quantify risks and their impact across systems; develop and prioritise mitigation measures, implement mitigation measures to improve their resilience and review and monitor their progress (as shown in Figure 1).

Welsh Water's RSA aims to provide the following benefits:

- Enable better decision making to build resilience for the future,
- Better communicate the approach to regulators and others, and
- Continuing to develop and implement leading-practice following Welsh Water 2050.

To inform the development of the resilient systems approach, Arup was commissioned to deliver two key stages of this work:

- Stage 1: A review of good practice examples from a variety of sources and sectors, and
- Stage 2: A review of the suitability of key case studies and their benefits. These aimed to address key challenges, identified by Welsh Water, with the development of their RSA.

As part of this work we closely collaborated with the asset strategy team who undertook wider engagement across Welsh Water, including engagement with Dŵr Cymru Executive Board, the Managing Directors meeting and Heads of Water and Wastewater.

2. Stage 1: Case study review

2.1. Introduction

To support the development of Welsh Water's Resilient Systems Approach (RSA), Arup has undertaken a review of 29 case studies of different tools and approaches that present learning opportunities for Welsh Water as it refines and develops its approach. The draft RSA incorporates four key steps:

- Risk identification and prioritisation,
- Development and prioritisation of mitigation options,
- Implementation, and
- Monitoring and review.

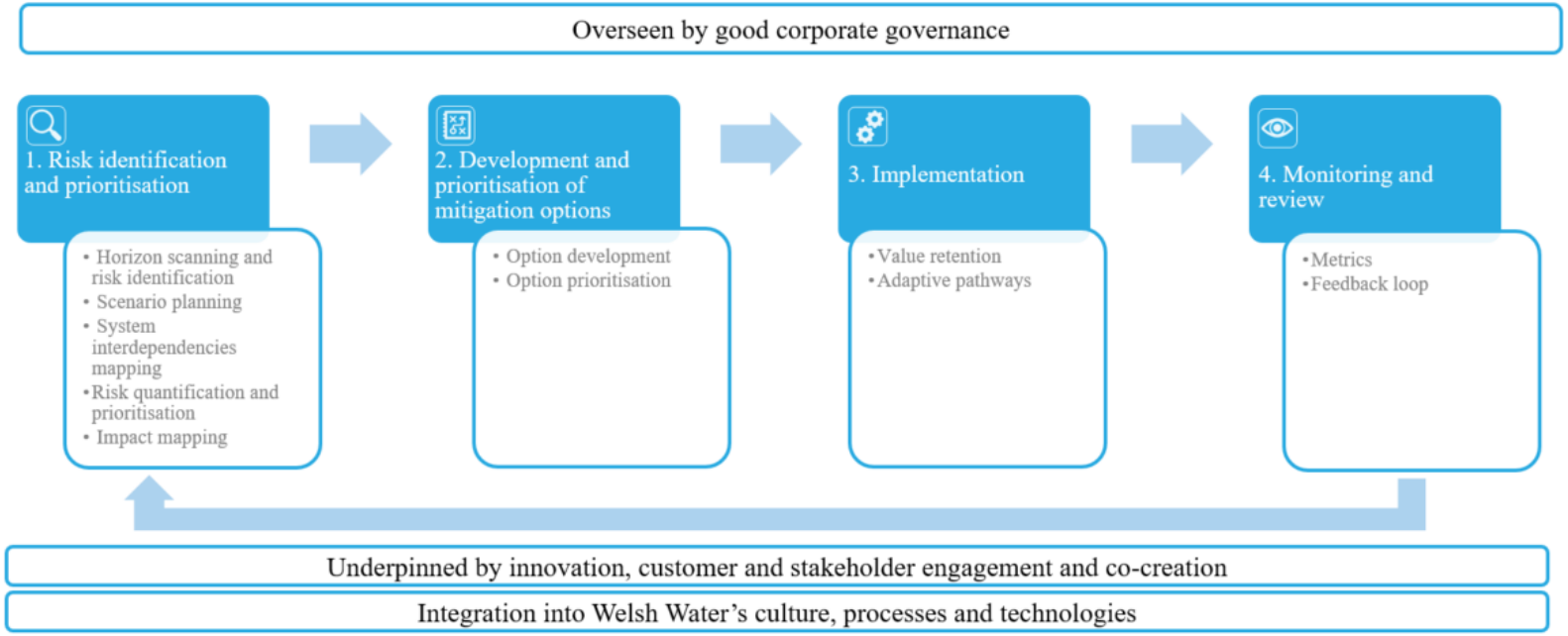


Figure 1: Daft RSA approach

Welsh Water's resilience in the round approach responds to risk at three levels:

- Strategic risks have widespread impact across multiple catchments or impact multiple services (e.g. water and wastewater networks) and cannot be mitigated by operational means without providing a reduced service to our customers.
- Tactical risks impact one service or a portfolio of assets and can be mitigated by operational means, however, it requires the Command system to be initiated.
- Operational risks impact at an asset level and have a localised impact.

As part of the development of the RSA, Welsh Water's thinking around this approach of assessing resilience as a tiered approach, is reflected through an emerging tiered approach to analysis. Each tier has a different amount of data required and different oversight.

These could be described as:

- Tier 1: Strategic - Qualitative models and indexes guide strategic risk analysis. The strategic risks are managed by the Welsh Water Executive Board through the corporate risk register, Welsh Water Resilience Wheel and Welsh Water 2050. Oversight of this level of risk management is provided by the non-executive Glas Cymru Board.
- Tier 2: Tactical - Simple models using quantitative data guide tactical risk analysis. The tactical risks are managed by the Directors of Service through the business risk registers and the Service Resilience approach. Oversight of this level of risk management is provided by the Welsh Water Executive Board.
- Tier 3: Operational - Complex modelling of interactions using significant quantitative data guide operational risk analysis. The operational risks are managed by the Heads of Service through the asset resilience scorecards and investment manager. Oversight of this level of risk management is provided by the Directors of Service.

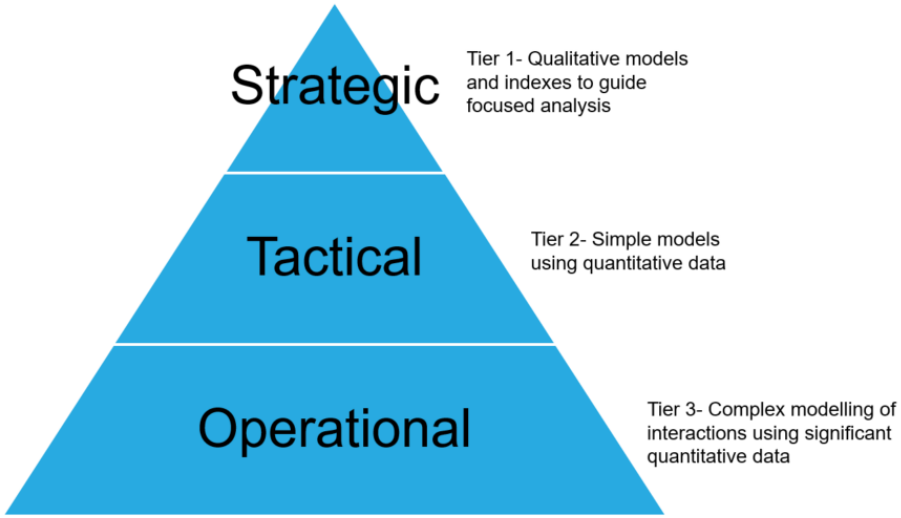


Figure 2: Different approach levels for resilience

2.1. The review

This review seeks to explore opportunities for learning to be applied to Welsh Water's RSA. Different approaches might be relevant at a strategic, tactical and operational level, depending on the business decisions that need to be taken at different times.

Arup has undertaken a review of approaches and methodologies, which support companies or stakeholders to embed resilience. Examples, have been drawn from the water sector, other asset-intensive sectors, and cities. Aspects of these approaches and methodologies could be incorporated into Welsh Water's RSA to strengthen their response to shocks and stresses.

Through this literature review alongside interviews with experts, we have assessed the applicability, suitability and ease of implementation of each of the 29 tools and approaches discussed above.

The summary table (Table 2) shows the results of this assessment and a short summary of the most relevant aspects of each case study. Figure 3 shows the various approaches and tools categorised according to the four steps of the proposed Welsh Water RSA methodology.

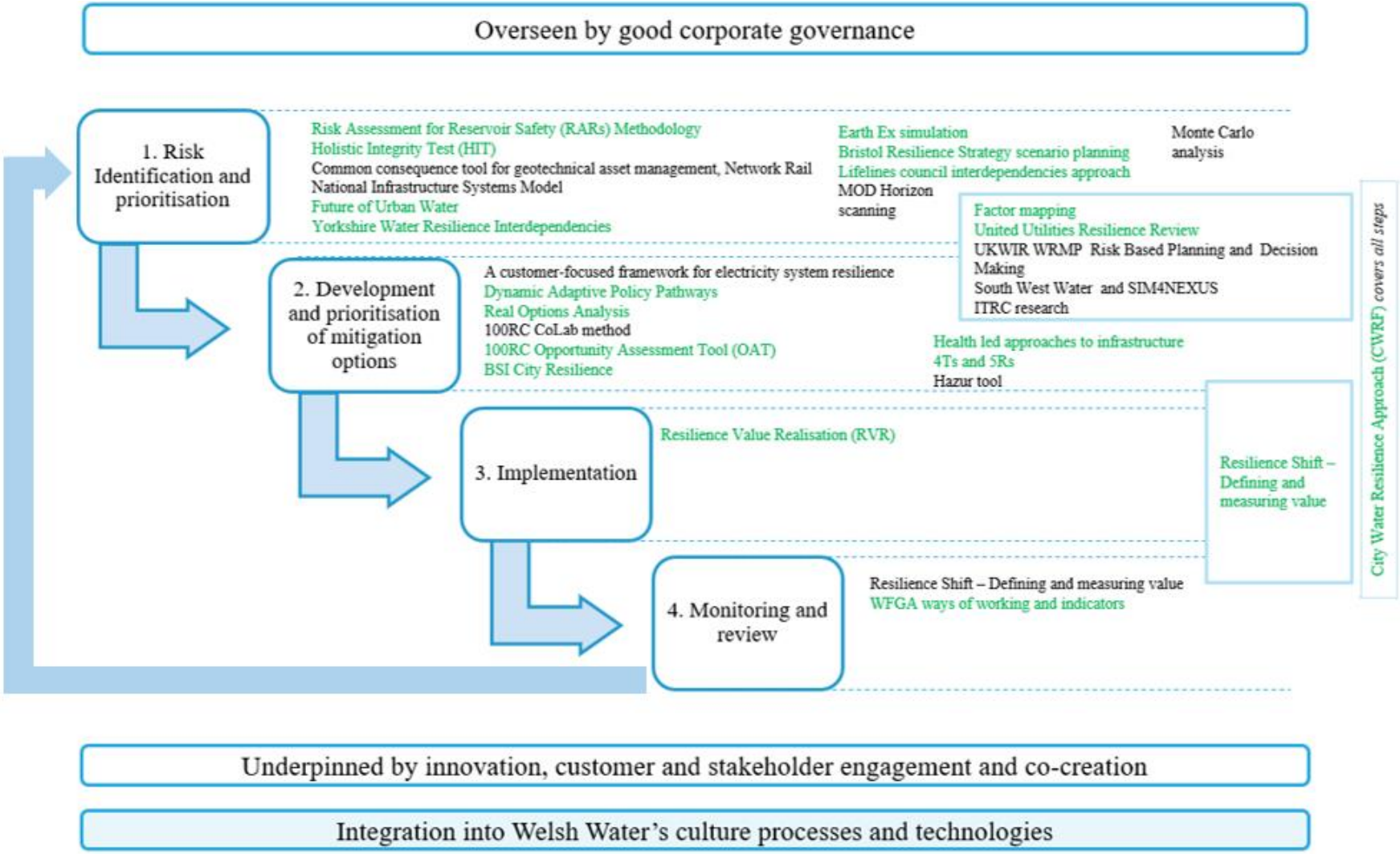


Figure 3: Case studies mapped onto the four steps of the proposed Welsh Water's RSA

Green highlights indicate a high suitability for incorporation Welsh Water's RSA. Note that some tools and approaches are suitable for more than one stage.

Table 1 Summary of applicability, suitability and overall assessment of the case study approaches to Welsh Water's resilient systems approach

Name of methodology	Which aspect is most useful?
Overall approach	
1. City Water Resilience Approach (CWRA)	The CWRA could provide a useful overall structure for assessing, building and monitoring resilience, if adapted to be suitable for water companies. The overall CWRA has five steps: 'understanding the system', 'assess urban water resilience', 'develop an action plan', 'implement the action plan' and 'evaluate, learn and adapt' reflects the draft RSA process. It includes a series of tools which could be useful for adoption or adaption by Welsh Water. These include a governance mapping tool and a qualitative and quantitative assessment framework. The identification of a resilience champion to facilitate the approach and stakeholder governance mapping are processes that could be adopted by Welsh Water. **Benefits:** A robust process to assess, qualitatively and quantitatively, the resilience of the urban water system which has a resilience champion and stakeholder engagement at its core and develops and implements resilience action plans.
RSA Step 1: Risk assessment and prioritisation	
2.Risk Assessment for Reservoir Safety (RARs) Methodology	This method includes a tier 1- qualitative assessments to tier 3- complex quantification of risk, which should be proportional to the consequence of failure. This tiered approach could be considered when implementing the overarching RSA approach to help advice the depth of assessment required. **Benefits:** Provides a tiered approach that can be used at different complexities to be most appropriate to the reservoir it is being used for. It therefore provides the opportunity to take a prioritisation approach that most suits the situation.
3. Holistic Integrity Test (HIT)	This is a multi-system approach and may require the cooperation of external stakeholders. It uses 'What If' workshops to develop risk identification, this could be a useful qualitative approach to take.

	Benefits: Highlights key weaknesses- so key coping parameters can be identified. It builds on current risk assessments and considers multiple systems allowing for an understanding of cascading impacts of risk through systems.
4. Common consequence tool for geotechnical asset management, Network Rail	This approach is focused on the failure of assets which could have serious consequences. In particular, Network Rail's 'Hazard Index' and 'Common Consequence Tool' uses historical failure records to improve predictions of failure likelihood. It is a robust method to manage asset risks with a focus on consequences rather than likelihood. However, it only considers one asset at a time and lacks the ability to take a systems approach including system interdependencies and cascading impacts. Therefore we do not believe that taking this approach would be suitable for the RSA approach. **Benefits**: A robust tool for risk prioritisation and quantification of consequences for single assets.
5. National Infrastructure Systems Model (NISMOD)	The model is primarily designed for multiple systems that have complex independencies at a national scale. Welsh Water's remit is only a small part of the total infrastructure asset base in England and Wales, so the tool itself may be of limited relevance. **Benefits:** Provides an overview of the whole of the UK's infrastructure, creating a prototype 'system-of-systems' modelling platform, to feed into investment decisions at a national scale.
6. Future of Urban Water	This approach to scenario development could be adapted and adopted by Welsh Water in the RSA process. It could identify drivers of change and build potential future scenarios of combined risks specific to the Welsh Water context. **Benefits:** Considers wide range of scenarios combining risks from social, technological, economic, environmental and political trends, in terms of how they could shape our urban water future.
7. Yorkshire Water resilience interdependencies	This approach to systems interdependencies could be used in the RSA assessment to give an overview of the linkages between systems and indicate the link between shocks and stresses, systems and impacts. A matrix of influence could be used to clearly identify how systems interact and how shocks and stresses cause cascading failures. **Benefits:** Clearly shows graphically how systems interact, helping to identify options for where to focus investment. It was identified by Ofwat as best practice.

8. Earth Ex simulation	The Earth Ex event approach focused on the key interdependencies and potential black sky hazards/cascading failures could be scaled. It provides a useful exercise in risk identification and prioritisation, helping to move the organisation on beyond simplistic risk identification and towards the systems-based approach. The Earth Ex style exercise could be done as part of, or alongside, system mapping and scenario planning, as part of looking specifically at system interdependencies. This approach could be used by Welsh Water to develop workshops to assess interdependent risk. **Benefits:** Encourages participation from a wide variety of organisations and provides a good opportunity for companies to identify key interdependencies and cascading failures.
9. Lifelines council interdependencies approach	This is approach to systems interdependencies mapping which could be adapted for Welsh Water. It includes a system interdependency matrix and dependency lines which could be an interesting method to use for risk prioritisation and could be used as a method to consider both internal and external risks. **Benefits:** Helps to identify interdependency 'choke points' where vulnerability, disruptions and interdependencies are more concentrated.
10.MOD Global Strategic Trends	A global horizon scanning approach looking 30 years into the future, to support long term planning and strategy development. Some of the outcomes of this approach would be applied to thinking of future Welsh Water scenarios. The second stage of the analysis related to geographical area is not relevant to Welsh Water, since this relates to a global geographic area. **Benefits:** Some themes used to generate scenarios could be relevant develop future scenarios for Welsh Water.
11.Monte Carlo analysis	Monte Carlo analysis is an approach for quantitative assessment of the level of risk that comes with taking a particular decision. Welsh Water could integrate Monte Carlo analysis into its RSA as a component of risk identification, but it should be part of a suite of tools that also bring in other, less quantitative methods, of assessment to ensure all aspects of resilience are considered. **Benefits:** Allows consideration of detailed probability distributions from many model-runs. It is computationally advanced.
12. Bristol Resilience	Four resilience scenarios were developed through workshops to feed into Bristol's resilience strategy. Welsh Water could undertake a similar exercise to better build in resilience to decision making processes.

Strategy scenario planning	**Benefits:** Testing decisions against variable futures can help decision makers develop a more nuanced, flexible response and to select decisions that will increase resilience into the future.
13. South West Water and SIM4NEXUS	The SIM4NEXUS approach is an academic methodology to assess the interdependencies between a water company and wider market drivers. The use of these models as an interactive 'Serious Game' to engage stakeholders and customers is a potential course of action to consider in the future when this method has been developed and tested. **Benefits:** Provides a systems-thinking model which is being simplified and made easy to use to engage with stakeholders and customers.
14. UKWIR WRMP Risk Based Planning and Decision Making	This approach sets out a wider framework for risk-based planning for water resource planning. It creates a process to choose different methods to identify the problem characterisation step, depending on vulnerability, increasing flexibility. It creates a suite of approaches and tools that decision makers can use to develop a robust approach to planning and option development. **Benefits:** Provides a flexible approach of using different tools to characterize problems depending on needs.
15. United Utilities Resilience Review	This approach to investment prioritisation could be used to prioritise a number of mitigation options to identify those that provide the most benefit for third parties and the environment. **Benefits:** A relatively simple method to priorities investment based on risk and impact which could be simple to apply to Welsh Water processes.
16. Factor Mapping	This is a workshop-based approach to identify the key factors that are valued to feed into prioritisation process. This could be implemented by Welsh Water as a method to develop options or to identify the key factors that Welsh Water value when developing an updated investment prioritisation methodology. **Benefits**: It is a qualitative collaborative approach to targeting interventions and investments and is an effective way of bringing together different stakeholders.

RSA Step 2. Development and prioritisation of mitigation options	
17. HAZUR tool	This is a city level software tool, created to support design, implementation and management of a resilience approach. As there is no evidence of the tool's successful application, it is potentially less useful for Welsh Water, though some learning could be taken from its method. **Benefits:** Allows simulation of risks based on real-time data. It includes consideration of aftermaths and cascade effects.
18. BSI City Resilience	This city level guidance approach for city stakeholders to work together to improve city resilience. Some stages of the methodology could be useful to adapt for the RSA, particularly the options prioritisation and evaluation stages. It has also identified useful tools for assessing interdependencies. **Benefits:** Allows consistent approach, independently recognised as providing a good standard. Part of its aim is to build integrated capacity and strengthen investment decisions.
19. Real Options Analysis (ROA)	This method that takes account of the value of uncertainty and flexibility and can be used as an alternative approach to traditional cost-benefit analysis (CBA) which assumes a specific future. **Benefits**: Able to take account of uncertainty and flexibility and take logical financial choices in a changing environment.
20. A customer-focused framework for electricity system resilience	This approach sets out a framework of a holistic view outside the traditional system boundaries for selecting energy policy options for the US with a focus on end-user experience and the customer experience. Welsh Water's customer-focused approach aligns well with the principles of this framework, and the organisation already considers measures to improve resilience that are beyond their traditional scope of control (such as domestic interventions). **Benefits:** Gives a holistic view of the wider sector, focusing on the experience of the end user.

21. 100RC CoLab method	The CoLab workshop brings together a range of stakeholders to collaborate to solve challenges that are too complex for any one sector or discipline to solve. Its format could be adapted to suit problem solving issues for development and prioritisation of mitigation options for Welsh Water's RSA. **Benefits:** Brings together multiple stakeholders to map root causes and identify overlaps.
22. 100RC Opportunity Assessment Tool (OAT)	The OAT tool supports cities to identify and prioritise possible initiatives, using a multi-criteria analysis approach called a 'Resilience Filter'. This filter could be adapted for a Welsh Water context and used as a method to prioritise initiatives and investments based on resilience value. **Benefits:** A useful method to prioritise investment based on resilience value.
23. Health led approaches to infrastructure	This is an approach to considers the capacity of infrastructure assets to provide health and wellbeing benefits. It uses various health and wellbeing focused dimensions to inform ongoing action, planning and investment. **Benefits:** The Health Asset Framework can widen the conversation around assessment of assets, providing a different perspective, particularly related to highlighting importance of non-physical infrastructure.
24. 4Ts and 4Rs	4Ts, of managing risk, and 4Rs, qualities of resilience, can be used as criteria or categorisation tools in assessment and prioritisation of mitigation options. **Benefits:** Using these categorisation tools helps to ensure any response or approach is broad in terms of its resilience characteristics.
25. Resilience Shift – Defining and measuring value	The approach is a useful way of framing individual risk quantification tools within the bigger picture of organisational resilience. Welsh Water should consider mapping its own full value chain and integrating these principles into its overarching Resilient Systems Approach. **Benefits:** Method to map full value chain, however it has no clear benefits over the resilience in the round assessment.

26. A capitals-based approach	This approach provides the opportunity to express non-financial impacts and dependencies in monetary terms so that different impacts can be compared. It could be used as a method to identify essential criteria for Welsh Water to incorporate into a multi-criteria analysis for investment prioritisation. **Benefits**: Ensures that all essential functions are considered equally in decision making processes.
RSA Step 3. Implementation	
27. Resilience Value Realisation (RVR)	This approach provides stakeholders with a shared understanding of resilience. Incorporating RVR into all investment decisions would help in embedding resilience thinking across the whole of Welsh Water's operations. **Benefits:** Facilitates the embedding of resilience thinking into BAU decision making and operations.
28. Dynamic Adaptive Policy Pathways	This approach uses adaptive pathways to create a flexible programme which can take uncertainty into account and supporting no-regret actions. It could be used for long term planning for investment and during implementation to identify when a specific approach is no longer providing expected benefits so a new approach is required. **Benefits:** Identifies opportunities, no-regret actions, and the timing of actions in a changing environment.
RSA Step 4. Monitoring and review	
29. WFGA ways of working and indicators	This sets out ways of working to deliver wellbeing goals and indicators to measure progress over time. The ways of working should be transferred explicitly or implicitly into Welsh Water's RSA. Setting clear metrics for building resilience should be part of the RSA, although not all of the WFGA indicators may be directly relevant to Welsh Water's activities. **Benefits:** Aligns with newly set out national legislation and supports a holistic approach to building resilience.

Findings

We found that for each of the four key steps of the RSA there are a number of approaches that could be learnt from and integrated into Welsh Water's approach.

We undertook literature review and structured interviews with experts who have used these approaches in practice. We asked these experts:

- How this approach worked in practice,
- If there were any parts of the approach that were particularly effective, and
- If there are any parts of the methodology that could be expanded or improved.

The overview of the key features of these approaches are detailed in Table 2. This also includes our rating of suitability and ease of implementation of these approaches. We suggest that those approaches rated as green are the most suitable to start implementing now and those rated amber or red would require further work and development before implementation.

A more detailed description of these case studies is detailed in Appendix A.

Table 2 Summary of applicability, suitability and overall assessment of the case study approaches to Welsh Water's resilient systems approach

RSA step	Key features / approaches that could be integrated	Learning from	Suitability	Ease of implementation
Overall approach	Assignment of a senior resilience champion	1. City Water Resilience Approach	Green	Green
	Stakeholder and governance mapping across the water cycle	1. City Water Resilience Approach - OurWater tool	Green	Green
1: Risk identification and prioritisation	Tiered approach to the assessment and quantification of risk	2. Risk Assessment for Reservoir Safety (RARs) Methodology	Green	Green
	Use of qualitative and quantitative indicators to assess resilience maturity	1. City Water Resilience Approach could be used to refine the Resilience Wheel	Green	Green
	Horizon scanning for future shocks and stresses	1. City Water Resilience Approach	Green	Green
		10. MoD Global Strategic Trends	Amber	Green
	Scenario development	6. Future of Urban Water	Green	Amber
		12. Bristol Resilience Strategy	Green	Amber
	'What-if' workshops for assessing interdependent risks	3. Holistic Integrity Test	Green	Amber
		8. Earth Ex simulation	Amber	Amber
	Quantification of failure	4. Network Rail Common Consequence Tool	Red	Amber
		11. Monte Carlo analysis	Green	Amber
	Interdependencies mapping	7. Yorkshire Water resilience interdependencies (PR19)	Green	Amber
		9. Lifelines Council interdependency mapping	Green	Amber

		5. National Infrastructure Systems Model (NISMOD)	Red	Red
2: Development and prioritisation of mitigation options	Options development	13. South West Water and SIM4NEXUS	Amber	Amber
		14. UKWIR WRMP Risk Based Planning and Decision Making	Amber	Amber
		15. United Utilities Resilience Review	Green	Amber
		17. HAZUR tool	Amber	Amber
		18. BSI City Resilience	Amber	Amber
		20. A customer-focused framework for electricity system resilience	Green	Amber
		24 .4Ts and 4Rs	Green	Green
	Options development workshops	16. Factor Mapping	Green	Amber
		21. 100RC CoLab method	Amber	Amber
	Multi-criteria Analysis	22. 100RC Opportunity Assessment Tool (OAT)	Green	Amber
		23. Health led approaches to infrastructure	Green	Red
		25. Resilience Shift – Defining and measuring value	Red	Amber
		26. A capitals-based approach	Green	Amber
		19. Real Options Analysis (ROA)	Green	Amber
3: Implementation	Adaptive pathways	28. Dynamic Adaptive Policy Pathways	Green	Amber
	Value retention	27. Resilience Value Realisation (RVR)	Green	Amber
4: Monitoring and review	Performance Metrics	29. WFGA ways of working and indicators	Green	Amber

3. Stage 2: Potential approaches to address Welsh Water's challenges

3.1. Overview of key challenge areas

Research to support key challenge areas

Welsh Water identified five key challenge areas for the development of the RSA by Welsh Water. Arup was commissioned to review current approaches and case studies that could be most effective to address these challenges. We were also asked to focus on strategic approaches (tier 1). These challenges, set out in Figure 4, are:

a) Governance
b) Risk prioritisation: assessment of low likelihood events
c) System interdependencies
d) Portfolio development
e) Adaptive pathways

This section covers each of these challenges in turn.

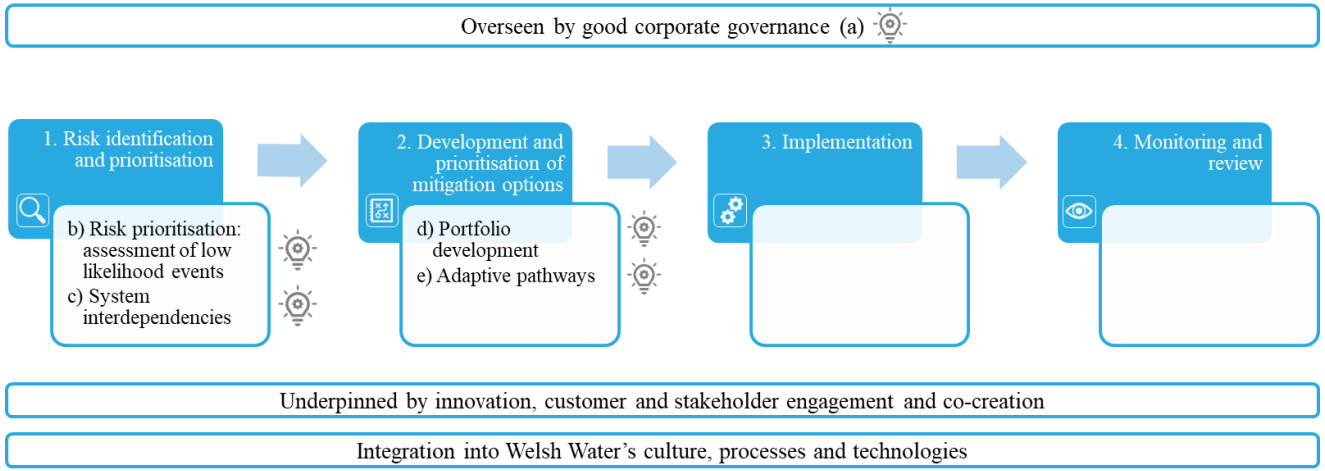


Figure 4: The key challenges we looked at in depth

3.2. Governance

Overview of the challenge

When new processes and methods are developed and implemented it is vital that they are overseen by good corporate governance. While Welsh Water do have robust governance systems in place, there are some opportunities to further strengthen this approach.

Findings

Based on our case studies and research we have identified five key opportunities for good governance. These are:

- Leadership and responsibilities,
- Information and data,
- Culture,
- Integrated processes, and
- Multi-stakeholder governance.

Leadership and responsibilities

Welsh Water current state

Welsh Water has a strong board ownership of Welsh Water 2050 and a good long term high-level understanding of long-term trends.

Opportunities to consider

We have identified that a key method of embedding resilience and driving change is to create a named role with a focus on championing resilience.

These champions must have the appropriate knowledge, resources and leadership power to bring together a range of people to build understanding and enhance resilience.

This is underpinned by research and experience from the City Water Resilience Approach (CWRA)[1] which establishes a city champion for resilience, and the 100 Resilient Cities[2] process that appoints a City Resilience Officer.

These roles and responsibilities should be clearly set and communicated to follow the UK Corporate Governance Code[3]. This focuses on facilitation of resilience rather than ownership of resilience as everyone should be empowered to own and enhance resilience across all projects.

Information and data

Welsh Water current state

Information and data on identified risks and risk management is held in Welsh Water's corporate risk register and supported by business risk registers across the business.

[1] Arup, 2019, The City Water Resilience Approach
[2] 100 Resilient Cities, http://www.100resilientcities.org/

[3] Financial Reporting Council, 2018, the UK Corporate Governance Code https://www.frc.org.uk/getattachment/88bd8c45-50ea-4841-95b0-d2f4f48069a2/2018-UK-Corporate-Governance-Code-FINAL.PDF

Opportunities to consider
Good governance is underpinned by a wide range of good data and information. Therefore, improving how information and data is used, shared and communicated would be highly valuable.

Clear risk information management would enable prioritisation of risks, escalation and movement between strategic, tactical and operational levels of risk management.

Risk and resilience processes and information could be held and worked with on user friendly dashboard. This would mean that users can access relevant information, appropriate for different audiences. This would ensure all documents are easy to find and update to date and that all staff were using the same scenario and horizon-scanning and risk prioritisation data. This would also show the clear procedures to manage risk and determine the nature and extent of risks as required by the UK Corporate Governance Code. A similar concept has been considered for implementation in the Bristol Resilience Strategy.

The dashboard could be used in key governance meetings, such as:

- Strategic Water and Wastewater business level risk meeting (planned to be undertaken twice a year),
- The Board in their resilience focused meeting, and
- Monthly Welsh Water executive meetings and Director of service meetings.

Culture

Welsh Water current state
Welsh Water has a strong culture, with a clear set of shared values. This culture is effective when dealing with reactive work, but can have limited capacity to implement proactive work to build long term resilience and capability.

Opportunities for Welsh Water to consider
Ensuring that Welsh Water's strategy and culture are aligned and focus on resilience is a key way to make sure that all the work undertaken will be aligned towards implementing Welsh Water 2050 in the long term. This is aligned with the UK Corporate Governance Code[4] principle where the Board need satisfy itself that the company culture is aligned with their long-term strategy.

Resilience capability building is vital to get everyone in the business to implement resilience into all the work they do. This could be in the form of on the job training or formal specific training. The 100 Resilient Cities programme has a large range of suggested tools and training materials to build resilience capability, which reflects how essential it is to embedding resilience into business-as-usual. These could be adapted for use by Welsh Water.

[4] Financial Reporting Council, 2018, the UK Corporate Governance Code https://www.frc.org.uk/getattachment/88bd8c45-50ea-4841-95b0-d2f4f48069a2/2018-UK-Corporate-Governance-Code-FINAL.PDF

Integrated processes

Welsh Water current approach

Welsh Water has a Strategic Asset Management Plan; however it does not include resilience and it is not used consistently by the business.

Opportunities for Welsh Water to consider

Based on our experience of working with other water companies, we have identified that ensuring that risk management processes are integrated is vital.

Multi-stakeholder governance

Welsh Water current state

Welsh Water works closely with external partners in various projects across the business. There is also a good understanding of the need for partnership working, clearly communicated in Welsh Water 2050.

Opportunities for Welsh Water to consider

A key part of many resilience improvements is to work in close collaboration with partners. This achieves increased resilience value, wider than a single organisation, and can share the responsibility for implementing resilience initiatives.

Understanding the stakeholders involved in the water system is key to improving collaboration with partners. This can be achieve by mapping responsibilities, accountability and interested stakeholders in the water system, map the existing relationships between them and highlighting the gaps.

This could be created by undertaking a stakeholder and governance mapping process, as created by the OurWater webtool developed by the City Water Resilience Approach, shown in Figure 5. This maps stakeholders, their responsibilities and jurisdictions over elements of the water system. This can help to identify areas where partnership working would be especially beneficial.

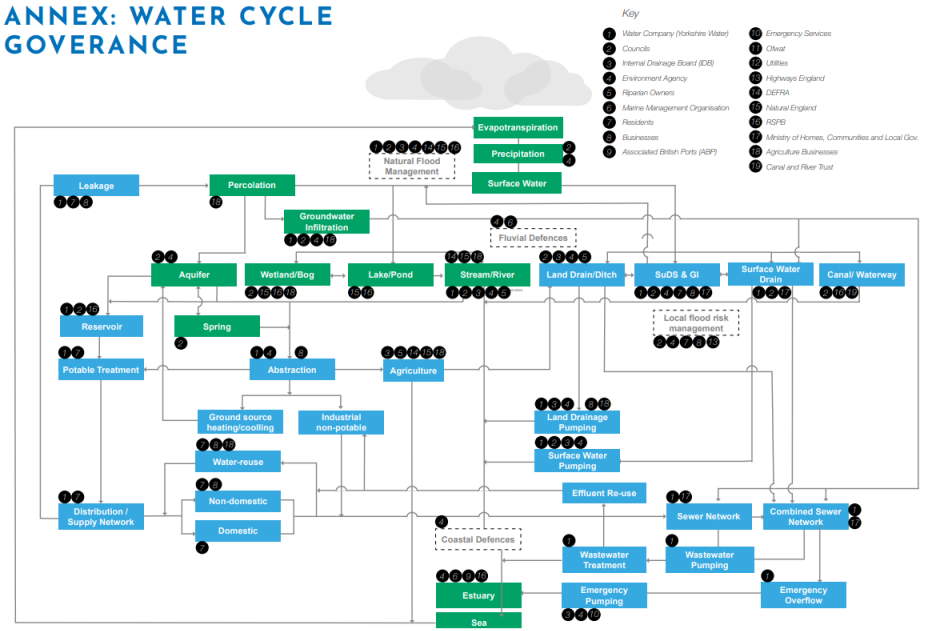


Figure 5: OurWater Water cycle governance diagram for the city of Hull from the CWRF. This maps stakeholders, their responsibilities and jurisdictions over elements of the water system.

3.3. Risk prioritisation: assessment of low likelihood events

Overview of the challenge.

A key focus of Ofwat's approach to resilience is the ability to prioritise high impact, low likelihood shocks or stresses. Many traditional risk prioritisation methods do not have the capacity to prioritise these types of shocks and stresses due to their low likelihood.

Welsh Water's current processes

Welsh Water has various methods of prioritising risks, through processes like the corporate risk register, supported by the business risk registers and Resilience Score Cards. Some work has been considered for bringing these together in the Service Resilience Approach, though this has not been implemented.

These approaches look at both likelihood and impact equally, meaning that high impact, low likelihood events are difficult to prioritise for investment.

Findings

Based on our case studies and research we have identified three key opportunities for resilience prioritisation. These are:

- Aligning strategic, tactical, and operational risk processes,
- Focusing on impact, and
- Prioritisation for critically severe consequences.

Aligning strategic tactical and operational risk processes

We have also identified that key to a robust approach to risk prioritisation is an aligned approach at all levels of the business. This is reflected in United Utilities approach to quantification of risks which is integrated into their corporate approaches so that the business has a shared method for capturing risks.

Focusing on impact

Focusing on the impact of a shock or stress, rather than the likelihood of that event happening could be a way to prioritise these low likelihood events. For example, the United Utilities' Resilience Review methodology for investment prioritisation for 123 sites had a greater focus on impact than likelihood. This assessment focused on criticality, impact of failure on the environment and third parties, and coping impact (using the 4Rs). While likelihood of failure was also assessed, it did not carry significant weighting when creating the Risk Priority Number for each site. This was developed to allow United Utilities to integrate low likelihood risks within normal investment planning.

An alternative approach is to skew the risk assessment for low probability events, with a greater focus on impact as used by Severn Trent Water. Their internal risk assessment[5] process includes the impact on public health, customers, environment, competition,

[5] Severn Trent Water, 2018, Statement of risks, strengths and weaknesses and final assurance plan for 2017/18

revenue and market confidence (reputational impact). This uses the matrix shown in Figure 6.

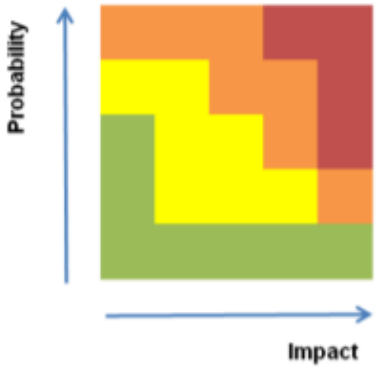


Figure 6: The Severn Trent Water Illustrative risk matrix.
In this matrix, red shows that highest priority risks, followed by orange, yellow and finally green. This shows that this approach is skewed towards the impact of events. [6]

Prioritisation for critically severe consequences

We suggest that learning from industries with critically severe consequences can provide learning on advanced quantitative assessment. However, a focus on mitigating any potential consequences no matter the likelihood can use significant portions of available investment.

There are examples of this in the nuclear industry. Due to the potentially severe consequences of failure, risk reduction measures aim to reduce the probability of exceedance to a very low value, typically 1 in 10,000. The industry is required by regulation to demonstrate continuously how these types of event are considered at every stage, from concept to detailed design. This can mean that investment is focused on reducing any nuclear risk, reducing the investment available to maintain the rest of their infrastructure. The nuclear industry uses advanced quantitative assessment methodologies developed over the last 4-5 decades, such as probabilistic risk assessment (PRA) to ensure risk-informed, performance-based regulation.

Each type of hazard involves a separate PRA (for example, a seismic PRA), and the development of these PRAs typically involve risk/hazard assessments (including use of hazard curves), probability assessments (including use of event trees and fault trees), and a structure fragility assessment.

However, research on the approach of the nuclear industry to risk assessment has noted that there can be a tendency to over-simplify the elements of risk to make them easier to analyse and evaluate, but this can distort the resulting decision.

Recommendations to reduce this effect include using sensitivity analysis, deliberation amongst experts, and enhancement of diversity and resilience capacity in addition to probabilistic risk analysis.

[6] Severn Trent Water, 2018, Statement of risks, strengths and weaknesses and final assurance plan for 2017/18

3.4. System interdependencies

Overview of challenge

As part of the response to PR19 business plan, Ofwat challenged Welsh Water to take a systems approach to resilience.

Welsh Water Current State

As shown in Welsh Water 2050 and the Resilience Wheel, Welsh Water have started to look at the business as a system at a high level. Welsh Water is already working closely with a number of external partners responsible for interdependent systems on a number of projects and understand how important collaboration is. However, there is no set process, embedded across the business for considering systems and their interdependencies.

Findings

Based on our case studies and research we have identified two key opportunities to improve identification of system interdependencies. These are:

- Matrix approach to system interdependencies, and
- Interdependencies mapping.

Matrix approach to system interdependencies

From our research we have identified that it is vital to show both the external systems and stakeholders that could impact Welsh Water's systems and the external systems that could be impacted by a Welsh Water failure. Taking this approach highlights the number of systems that are dependent on a system allowing a true understanding of the consequences of a system failure. It also highlights potential areas for partnership working with external stakeholders.

We suggest that an effective approach to assessing the system interdependencies could be a matrix methodology. This matrix looks at how the key systems and shocks and stresses interact based on an adapted methodology from academic papers Kunze et al 2015[7] and Seppanen et al 2018[8]. This is a similar methodology to that used by Yorkshire Water for their interdependencies mapping[9].
If a tiered approach to complexity was considered, then the following methodologies could be considered:

- Tier 1 (Strategic): assessing the interaction between key systems and key shocks and stresses at a high level, as shown in Figure 7.

[7] Oliver Kunze, Gebhard Wulfhorst, Stefan Minner, Applying Systems Thinking to City Logistics: A Qualitative (and Quantitative) Approach to Model Interdependencies of Decisions by various Stakeholders and their Impact on City Logistics, Transportation Research Procedia, Volume 12, 2016, Pages 692-706, https://www.sciencedirect.com/science/article/pii/S2352146516000235

[8] Seppanen, Hannes & Luokkala, Pekka & Zhang, Zhe & Torkki, Paulus & Virrantaus, Kirsi. (2018). Critical infrastructure vulnerability—A method for identifying the infrastructure service failure interdependencies. International Journal of Critical Infrastructure Protection. 10.1016/j.ijcip.2018.05.002. https://www.researchgate.net/publication/325196934_Critical_infrastructure_vulnerability-A_method_for_identifying_the_infrastructure_service_failure_interdependencies

[9] Yorkshire Water, 2018, Appendix 12b, Water Resilience in Yorkshire appendix

- Tier 2 (Tactical): a more detailed matrix breaking down the internal systems and the detailed risks identified in the resilience risk register and how all of these more detailed systems are interdependent.
- Tier 3 (Operational): a more detailed data dependent approach, learning from the Sim4nexus approach.

		Potential impact					
Scenario 1		Internal			External		
		System 1	System 2	System 3	Stakeholder 1	Stakeholder 2	Stakeholder 3
Internal	Shock or stress 1	1	2	1	0	1	1
	Shock or stress 2	0	0	1	2	3	1
	Shock or stress 3	0	2	2	1	1	1
External	Shock or stress 1	0	2	1	2	2	1
	Shock or stress 2	1	2	2	1	0	0
	Shock or stress 3	0	0	0	1	1	1
Internal	System 1		1	1	0	0	3
	System 2	1		1	0	0	1
	System 3	0	0		0	2	1
External	Stakeholder 1	1	1	1		0	1
	Stakeholder 2	2	2	1	0		1
	Stakeholder 3	1	1	2	2	1	

Figure 7:Possible matrix approach to assessing the strength of system interdependencies. This could be undertaken for many systems, shocks and stresses, and stakeholders but only three of each have been shown in this for indicative purposes.

It uses the following scale to describe the strength of interdependencies:

- 0- no connection/ impact
- 1- weak connection/small impact
- 2- medium connection/ impact
- 3- Strong connection/impact.

This approach could be used to understand the interdependencies between shocks and stresses.

		Internal			External		
		Shock or stress 1	Shock or stress 2	Shock or stress 3	Shock or stress 1	Shock or stress 2	Shock or stress 3
Internal	Shock or stress 1		1	0	0	1	1
	Shock or stress 2	1		3	2	1	1
	Shock or stress 3	2	1		2	0	0
External	Shock or stress 1	1	2	0		1	1
	Shock or stress 2	1	2	0	1		0
	Shock or stress 3	1	1	0	1	3	

Figure 8:Possible matrix approach to assessing the strength of shock and stress interdependencies (this would use the same scale approach as the system interdependencies).

This matrix approach could be undertaken for each scenario developed for Welsh Water. This would show how the strength of interaction or impact would change in the future depending on how the world develops.

This matrix would ultimately create an interdependencies score, which could feed into the investment prioritisation approach.

Interdependencies mapping

While the matrix approach is an effective way to collect and analyse the interdependencies data, we suggest that creating a visual map of this data is a more effective way to communicate the importance of systems.

This could be shown in a single system focused diagram, as undertaken by Yorkshire Water for their PR19 resilience appendix[10], shown in Figure 10. This focuses on systems individually and shows the interactions these have with internal and external systems individually.

Alternatively, all the interdependencies could be displayed on one figure to help overall planning.

Chord diagrams are a potential method to show all of the key interdependencies felt across all the systems of a business and their sphere of influence in one diagram. There is also the potential show just the interdependencies and linkages by just one system or just one shock or stress to highlight how cascading impacts occur, in an interactive format.

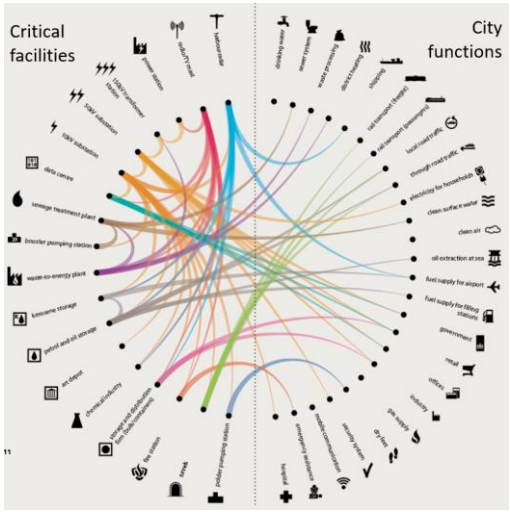


Figure 9: Example Chord diagrams that could be adapted for Welsh Water[11]

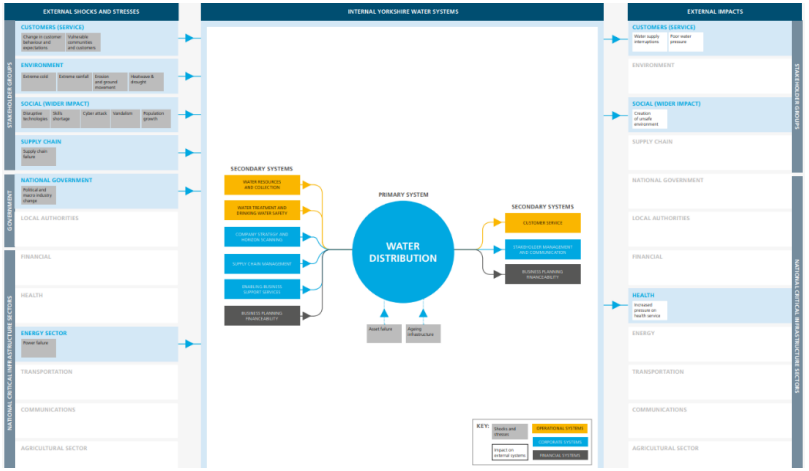


Figure 10: Yorkshire Water's single system approach

[10] Yorkshire Water, 2018, Appendix 12b, Water Resilience in Yorkshire appendix

[11] C40, 2017, infrastructure interdependencies and climate risk report

Potential systems and external stakeholders

Potential **internal** systems to consider:	Potential **external** stakeholders and their systems to consider:
Operational: • Water resources (reservoirs, rivers, raw water, catchments) • Water treatment • Water distribution • Sewerage (inc CSOs) • Sewage treatment • Sludge treatment and disposal • Supply chain management • Energy generation • Information systems *Corporate* • People • Customer services and stakeholder engagement • Strategy and planning *Financial* • Financial systems	• Customers • Community groups • Supply chain • Regulators • Communications providers • Transportation providers • Energy providers • Health and emergency services • Financial services • Local Authorities • National Government • Industry • Agriculture and land owners • Environmental bodies • Tourism and recreation

3.5. Portfolio development-balancing investment between portfolios

Overview of challenge

Effective portfolio management sets a standard process for investment prioritisation, to ensure that selected investments provide the most value. Embedding resilience into this process is in development in various sectors, however no tried and tested approach is yet available.

Welsh Water's current state

Welsh Water currently identifies the investment required across the business through Investment Manager and through deliberating in the PR19 Investment Prioritisation Group.

Findings

Based on our case studies and research we have identified three key opportunities to improve portfolio development. These are:

- Collaborative benefits identification,
- Resilience focused multi-criteria analysis, and
  Retaining value approach.

Collaborative benefits identification

Investments prioritisation should be based on the outcomes that the company most values and the benefits that it is key for them to achieve.

These key benefits and values can be collaboratively developed and agreed, both within the business and with key external partners and stakeholders. This approach will ensure that the objectives of all parties involved are understood and represented and identify similar strategic objectives to enable closer partnership working.

Factor mapping, a method for high level qualitative analysis, is a potential workshop process to identify these key factors to measure. To do this stakeholders and partners come together for a workshop where they agree a system boundary and appropriate list of factors (up to eight factors). These factors are then compared for strength of relationship to each other (on a five-point scale). This approach has been used in the international development sector and found to be effective in bringing together diverse viewpoints.

Resilience focused multi-criteria analysis

Another option is to identify these values and benefits with a focus on resilience, creating a clear investment prioritisation methodology with resilience at its core. This will ensure that all programmes both support the Welsh Water's mission and are resilient in the long term.

Welsh Water could focus on ensuring that resilience is a key part of this process, taking inspiration from United Utilities which uses the 4Rs (resistance, reliability, redundancy and response and recovery) in its decision making.

Alternatively, a more detailed approach would be to take a 'Resilience Filter' method, adapted from the Opportunity Assessment Tool (OAT) used by 100 Resilient Cities[12].

This could include multi-criteria analysis using the following questions:

- Which shocks or stresses is the initiative addressing?
- Which of the Resilience Wheel sub-themes is the initiative addressing?
- Which of the qualities of resilience (the 4Rs of resistance, redundancy, reliability, response and recovery) is the initiative addressing?
- Which of the internal systems is the initiative improving?
- Which of the external systems is the initiative improving?

This could be combined with further questions, incorporating the 6 capitals approach and the 4Ts of resilience (transfer, tolerate, treat and terminate).

Resilience focused investment prioritisation processes have also been created, these are referenced in BS67000 City Resilience[13] and have been taken forward for Bristol Airport and Manchester Airport. This is a method that identifies importance of a system, based on its interdependence and value. It creates a resilience baseline based on Resilience Demand, made up of the shocks and stresses, and Resilience Capacity, made up of the mitigation in place and the adaptive capacity of the system. The impact of possible investments can be compared to this baseline.

A further alternative method for multi-criteria analysis is the capitals approach. This approach aims to ensure that all impacts, both positive and negative, on all the essential functions of the organisation are equally considered and not purely focused on financial capitals.

An example of this approach in practice is Yorkshire Water's Six Capitals Approach to their Decision Making Framework (DMF)[14]. These six capitals are financial, manufactured, natural, human, intellectual and social and are described in more detail in Figure 11. Within the DMF, they have a 'six capitals impact assessment tool' which quantifies risk and value to optimise investment and manage decisions on operations and assets considering all six capitals.

Figure 11: Yorkshire Water's six capitals definitions

[12] 100 Resilient Cities, 2018, Opportunity Assessment Tool https://www.100resilientcities.org/tools/opportunity-assessment/

[13] BSI, 2019, BS67000 City Resilience Guide

[14] Yorkshire Water, 2018, The Six Capitals in our Decision Making Framework https://www.yorkshirewater.com/sites/default/files/Yorkshire_Water_DMF_website_case_study.pdf

Retaining Value

Having determined and prioritised the best option to deliver resilience value, it is important to develop an approach that enables this value to be retained, as projects and programmes move into delivery.

Through the 100RC programme, an approach to resilience value realisation was developed. Welsh Water can learn from the concept behind this approach. This could be by making tweaks to the current gateway process for capital projects, including reviews against the resilience objectives outlined at the start.

As with the prioritisation process, these could encapsulate the same criteria as set out in an MCA, including for example delivering in a way that embodies resilience qualities, mitigating shocks and stresses, and enhancing systems.

Figure 12: A 100 Resilient Cities OAT workshop in operation

3.6. Adaptive Pathways

Overview of challenge

Through Welsh Water 2050, Welsh Water has considered the investments that they want to deliver in the long term. Planning for these investments is difficult. While you can plan for known shocks and stresses, to be truly resilient planning also needs to consider unknown shocks and stresses, or unknown unknowns. It is not an easy task to create a portfolio of investments which takes uncertainty into account.

Findings

Based on our case studies and research we have identified two key opportunities to use adaptive pathways. These are:

- Portfolio planning- adaptive pathways mapping, and
- Portfolio review- tipping points

Portfolio planning- adaptive pathways mapping

We suggest that a highly effective method of long term planning and programme development under uncertain conditions is to use adaptive pathways. It is an analytical approach to explore and sequence a set of possible actions over time under changing conditions[15].

It enables the creation of a balanced programme of highly robust actions, which are often expensive and cause large impact, with other actions, that are easier to implement but may not last as long. It shows a way to navigate and plan for uncertainty looking at different costs, benefits and co-benefits.

This method has been used by water companies in the development of their Water Resource Management Plans (WRMPs) for their PR19 plans. For example, Thames Water have used this method in their PR19 Water Resources Management Plan (WRMP) looking to 2100[16], in United Utilities for their water trading scenarios[17], and in Affinity Water's draft final WRMP.

This can be used in conjunction with scenario planning. All scenarios can be shown on an adaptive pathway map, along with all the potential mitigation actions that could be implemented (an example is shown in Figure 13). This can help identify the correct action to undertake now, and which other actions can then be undertaken in the future, with little wasted resources.

[15] Haasnoot et al., 2013, Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world, Global Environmental Change

[16] Thames Water, A Resilient Water Supply- adaptation pathways https://sustainability.thameswater.co.uk/-/media/Site-Content/Corporate-Responsibility/CRS-201617/A-precious-resource/Case-studies/update/A-resilient-water-supply---adaptation-pathways.pdf

[17] United Utilities, Revised draft WRMP https://www.unitedutilities.com/globalassets/z_corporate-site/about-us-pdfs/water-resources/revised-draft-wrmp19---main-report.pdf

Portfolio review- tipping points

The use of tipping points helps to identify when an action no longer meets a specified objective. When a tipping point is reached, then other actions are needed, and this pathway provides a sequence of possible actions.

As time passes, and future scenarios change, then actions can continue to be flexible to meet these changes.

Working towards preferred pathways with stakeholders creates a discussion on adaptive plan. This enables working short-term actions whilst also looking at what this means in the long-term.

Potential future uses for Welsh Water

This is a flexible process that could be used at strategic, tactical or operational levels.

We suggest that the greatest potential benefits of this would be to use this methodology to map the portfolio of investments in Welsh Water 2050. Therefore, instead of the potential actions shown in Figure 13 these would be the strategic responses, and the level of investment could be shown in the adaptation pathway.

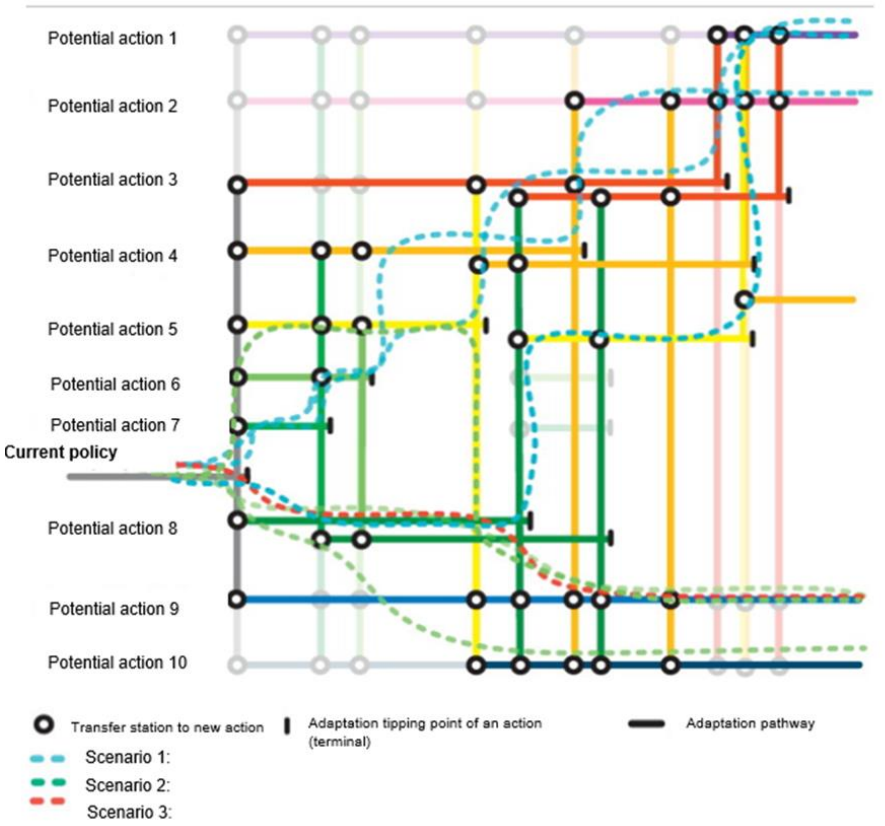


Figure 13: Example approach for multiple scenario based adaptive pathways[18] showing a sequence of possible actions. Shows multiple scenarios and the potential actions that could be undertaken to reach a set goal. These are a mix of high costs long term actions and lower costs short term actions.

[18] Adapted from Haasnoot et al., 2013, Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world, Global Environmental Change

4. Recommendations and next steps

Based on our analysis and research, we recommend the key next steps for Welsh Water to develop these new approaches. These are based on our assessment of suitability and ease of implementation. We have set out timescales based on these factors and a sequence to activity. There are seven main activities:

1. Identify resilience lead
2. Interdependencies mapping
3. Stakeholder mapping
4. Adaptive pathways
5. Resilience capacity building
6. New information sharing platform
7. New investment planning and delivery

1. Identify resilience lead

- This role should have enough knowledge of resilience, be in a position of leadership and have suitable resources to implement resilience in practice.
- Identify a role at executive level, who can champion and facilitate resilience.

Timescale: Before the end of AMP6

Benefits: This role will provide a catalyst for change in Welsh Water and support the delivery of Welsh Water 2050.

2. Interdependencies mapping

- Determine internal systems and external stakeholders for analysis.
- Undertake interdependencies mapping matrix.
- Create interdependencies map (potentially with a Chord Diagram).

Timescale: By end of 2020

Benefits: This aims to improve systems understanding and provide a more robust risk approach.

3a. Stakeholder mapping

- Identify all the partners and stakeholders both across the water cycle and more widely in the region that Welsh Water partner with and are impacted by service provision.

- Identify the responsibilities of these stakeholders.
- Create a map of these interactions and responsibilities.

Timescale: By end of 2020

3b. Priorities options for new collaborative working

Use this mapping of responsibilities, accountability and interest of stakeholders to priorities new areas for collaborative working.

Timescale: By end of 2021

Benefits: This will provide an integrated and consistent way to identify and collaborate with stakeholders and partners to deliver the aims of Welsh Water 2050.

4a. Adaptive pathway for Strategic Responses

- Use the adaptive pathway approach to assess process and the portfolio approach of the strategic responses within Welsh Water 2050.

Timescale: By mid-2021

4b. Development of a wider adaptive pathway approach

- Consider how the adaptive pathways approach could be used as a prioritisation method for wider investment portfolio work and develop a consistent methodology.

Timescale: By end of 2022

4c. Implement adaptive pathways more widely

- Implement the methodology created to support the development of PR24.

Timescale: by end of 2025

Benefits: This will provide a consistent and robust method for Welsh Water to plan for uncertainty and ensure that the aims of Welsh Water 2050 will be achievable.

5a. Develop capacity building programme

- Identify areas where there are key resilience knowledge, skills and behaviour gaps.
- Develop a resilience capacity building programme that could be used for the company.
- Implement programme.

Timescale: By mid-2020

5b. Deliver trial element of capacity building programme

- Deliver programme to key member of staff and adapt and build upon this programme based on feedback from this trial.

Timescale: By mid-2022

5c. Embed resilience capacity building approach

- Deliver this programme across the business.

Timescale: by end of 2025

Benefits: This will build the capacity and skills of Welsh Water's people to respond to shocks, stresses and uncertainty and ensure that Welsh Water 2050 can be delivered.

6a. Development of information sharing platform for risk and resilience

- Develop new ways of hosting risk and resilience information to support sharing of up-to-date information.

Timescale: By end of 2021

6b. Implement information sharing platform

- Deliver this new information sharing platform to support the sharing of risk and resilience information.

Timescale: by end of 2023

Benefits: This will provide a robust and integrated approach to understanding risks, systems and strategy.

7a. Scope new investment planning and delivery

This should include a consolidation of current approaches to investment planning and should consider integrating in new approaches such as:

- 4Rs scoring mechanism,
- The outcomes of the system interdependencies mapping,
- Using the skewed low likelihood and high impact risk matrix, and
- A capitals approach.

Timescale: By end of 2020

7b. Develop investment planning and delivery process

- A development of a full investment planning process which includes the key factors that Welsh Water most value.

Timescale: By end of 2022

7c. Implement investment planning and delivery process for PR24

- Implementation of the new process to support the development of PR24.

Timescale: By end of 2025

Benefits: This will provide a robust and integrated approach to embed risk and resilience into key investment decisions ultimately leading on to the successful delivery of Welsh Water 2050.

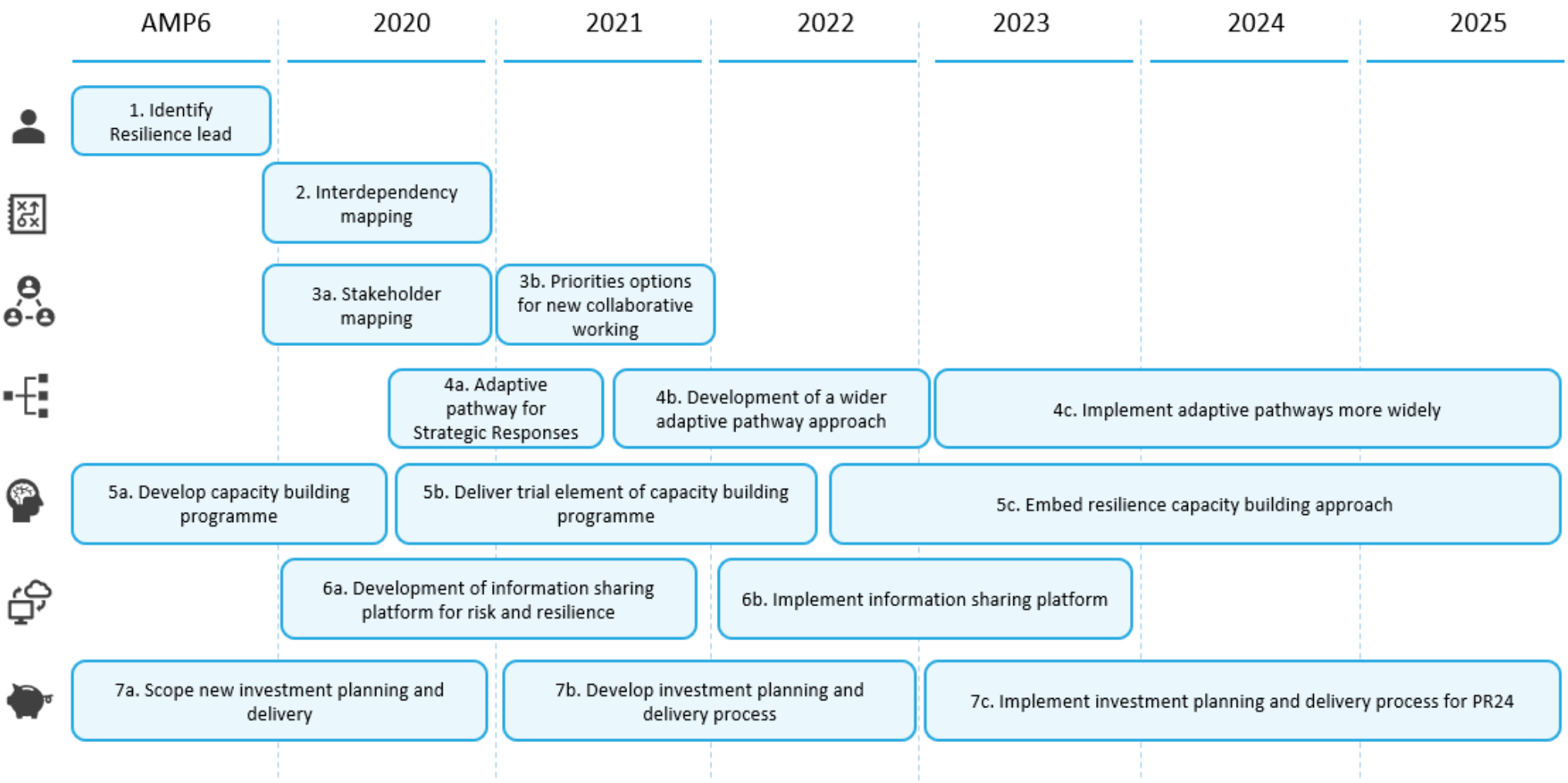


Figure 14: Key next steps for opportunities to implement

A. Appendix A: Case Study Review

I. Case Study: City Water Resilience Approach

Developed by	*Arup and 100 Resilient Cities*
Sector	*Local Government*
Applicable RSA Step(s)	*1,2,3*
STO	*Strategic*
Suitability	*Green*
Ease of implementation	*Green*

Overview

The City Water Resilience Approach (CWRA) responds to a demand for innovative approaches and tools that help cities build water resilience at the urban scale, based on principles of 'providing water, protecting urban areas from water-relate shocks and stresses, and connecting the city through water-based transportation and water in the urban realm'.

The CWRA is an approach to building capacity and water resilience in cities, which includes additional tools that help target specific challenges. These tools include the City Water Resilience Framework (CWRF), an assessment framework with qualitative and quantitative indicators and 'OurWater' digital tool for understanding the interdependent systems involves in the city's water catchment and the governance of the interdependent system.

Methodology

The CWRA outlines five key steps, as follows:

1. **Understand the system:**

The first stage focuses on defining the basin(s) upon which the city depends and engaging with the individuals and organisations that have jurisdiction over different elements of the water cycle in these basin(s). Key methodologies and tasks in this stage include:

- Establishing a city champion for resilience;
- Mapping the physical water system and its interdependencies with external systems and mapping the governance of the water system; and
- Holding a multi-stakeholder inception workshop.

The 'OurWater' tool supports this stage of the process.

2. **Assess Urban Water Resilience:**

The assessment of urban water resilience uses the qualitative and quantitative indicators in the City Water Resilience Framework through workshops to assess the resilience of the urban water system and identify areas of strengths and gaps.

3. **Develop an action plan:**

The development of an action plan is based on the diagnostics and assessments from the previous steps. Through a series of visioning workshops, stakeholders identify clear objectives and set a common vision. They then develop actionable initiatives and projects that will

build city water resilience. The action plan may include projects already underway as well as ideas for new initiatives and should respect other existing and planned city strategies.

4. **Implement the action plan**

Implementation of the action plan needs to recognise that the plan should be dynamic and evolving over time. Continuous evaluation and the ability to review progress and revisit the priorities identified allows for an adaptable approach.

5. **Evaluate, learn and adapt**

The fifth stage focuses on monitoring progress and ensuring that the process is active, and that elements of learning, transforming and adapting are embedded. Tasks include:

- Evaluation of the implementation of resilience measures
- Analysis of changes in context including horizon-scanning for future shocks and stresses, and
- A re-assessment of objectives for next period.

Analysis

The CWRA provides a globally applicable and structured approach to building city water resilience. The involvement of multiple stakeholders throughout the process aims to build partnerships through to implementation. The application of specific tools within each step of the process helps facilitate a rigorous but adaptable approach.

Suitability for RSA

The CWRA if adapted to become a water company resilience approach would provide a useful overall structure for assessing, building and monitoring resilience. The tools may not all be as useful in a water company context but may provide a useful basis on which to develop a Welsh Water specific process.

Steps 1 and 2 ('understand the system' and 'assess urban water resilience') are particularly relevant for the first element of the RSA approach (risk identification and prioritisation). It would be beneficial for Welsh Water to identify a senior resilience champion as a first action. Steps 3 and 4 ('develop an action plan' and 'implement the action plan') are most relevant to the 'development and prioritisation of mitigation options' aspect of the RSA. Step 5 ('evaluate, learn and adapt') is equivalent to the fourth stage of the RSA that relate to monitoring and review, as well as addressing the underpinning principles of integration into Welsh Water's culture, processes and technologies.

References

Arup, 2019, The City Water Resilience Approach

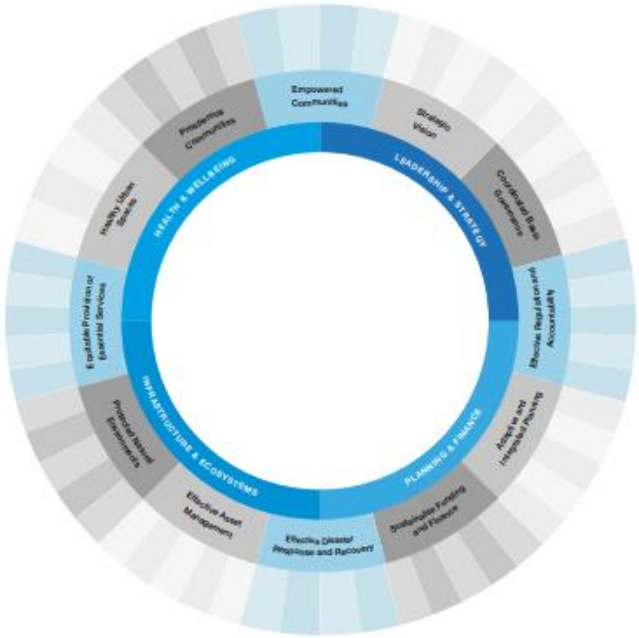


Figure 15: The City Water Resilience Framework (CWRF), one of the tools used in the City Water Resilience Approach.

II. Case Study: Risk Assessment for Reservoir Safety (RARs) Methodology

Developed by	*Environment Agency*
Sector	*Water*
Applicable RSA Step(s)	*1*
STO	*Tactical and Operational*
Suitability	*Green*
Ease of implementation	*Green*

Overview

The methodology aims to ensure acceptable levels of risk at dams and to prioritise investment in the portfolio of dams to improve the risk profile across the portfolio. It aims to meet a wide range of reservoir owner/undertaker and industry needs as well as fitting with current UK government flood risk assessment policy and practice.

Methodology

The assessment is arranged around three main steps:

1. Risk identification (including failure modes and consequence),
2. Risk analysis (including likelihood of failure), and
3. Risk evaluation (including tolerability of risk).

The robustness of the assessment increases through the tiers, with Tier 1 being the least and Tier 3 being the most robust. Tier 1 is qualitative and is designed as an initial data collection and risk assessment exercise. Tier 2 builds on this and provides a basic quantitative estimate of reservoir risk. Tier 3 introduces more complex methods for assessing and quantifying risk. It is applicable both to individual reservoirs as well as portfolios of multiple reservoirs.

Analysis

Overall, it provides a robust and methodological approach to reservoir risk management. The methodology does not stipulate specific methods of quantification but includes suggested references that can be adopted by the user.

Suitability for RSA

Step 1: Risk Identification and quantification

The robustness of risk or resilience assessment should be proportional to the consequence of failure, and the ‘three tier’ approach in the methodology demonstrates how an approach can take this into account. The tiered assessment process as part of RARs could be used as part of an RSA, to ensure quantification is carried out where risks are appropriately high.

References

Environment Agency, 2013, Guide to risk assessment for reservoir safety management

Environment Agency, 2013, Guide to risk assessment for reservoir safety management, Piloting summary report

Figure 16: Welsh Water Reservoir

III. Case Study: Holistic Integrity Test (HIT)

Developed by	*Arup*
Sector	*Infrastructure Systems*
Applicable RSA Step(s)	*1*
STO	*Strategic, Tactical*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

The Holistic Integrity Test (Dobson, et al., 2016) was developed in response to the extreme challenges posed by rising sea levels and other impacts from climate change.

It can be used to assess the ability of a variety of types of infrastructure to cope with shocks and stresses. It considers all hazards, including 'above design standard' shocks and analyses how different parts of a system will cope before, during and after the event. The test has three risk reduction goals:

- Sustaining safety functions;
- Managing a crisis situation; and
- Recovering to a safe and stable state.

The test specifically addresses the shortcomings of more traditional risk management approaches which do not analyse the consequences of 'exceedance' events, and do not consider indirect effects outside the system boundary.

Methodology

The approach considers risk from a holistic systems perspective. This considers how a shock scenario may impact a system based on the vulnerability of that system, the coping strategy and plan for response and recovery in a mainly qualitative manner.

Firstly, shocks and stresses are grouped, and the impact is assessed by group, meaning the impact is the focus rather than the specific shocks or stress. The impact is assessed by 'what-if' testing the system to understand performance. This is typically performed in a structured 'what-if' workshop. The system is then modelled to quantify losses before, during and after the event, which builds a detailed pictures of system vulnerabilities and the coping cycle. It can also help non-structural actors (such as emergency services) to 'expect the unexpected' during an extreme event. Severe Shock Event Risk (SSER) is then quantified as a function of 'exposure before', 'damage during' and 'ability to recover after'.

This process complements a company's risk assessment and goes into more detail where weaknesses and vulnerabilities are identified. Its allows a company to undertake a crisis scenario and identify what they would be unable to cope with.

Analysis

The approach is useful to consider severe shocks, or 'black swan events'. It has been applied to several real-world examples, including the Fukushima disaster of 2011, and serious flooding events in the UK. It considers the indirect impacts of serious events, beyond the individual asset in question.

The 'what-if' workshop methodology is useful as a vulnerability test. However, the subsequent in-depth system modelling is complex and may be too time-consuming and involved to implement as a business-as-usual approach.

Suitability for RSA

There is an opportunity to integrate learning into the RSA step 1. Risk identification and prioritisation
The 'what-if' workshop methodology for testing the impact of shocks and stresses on multiple systems could form a core part of Welsh Water's approach when considering the risk of severe events to their business and interdependent systems.

References

Dobson et al., 2016, The Holistic Integrity Test (HIT) - quantified resilience analysis

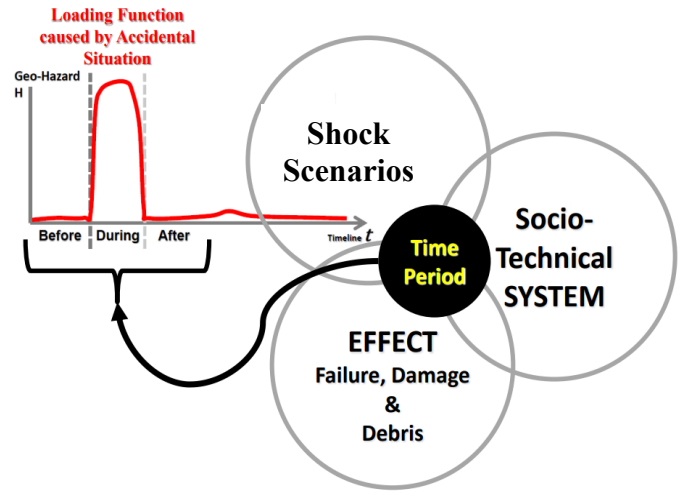


Figure 17: The key steps in the HIT process

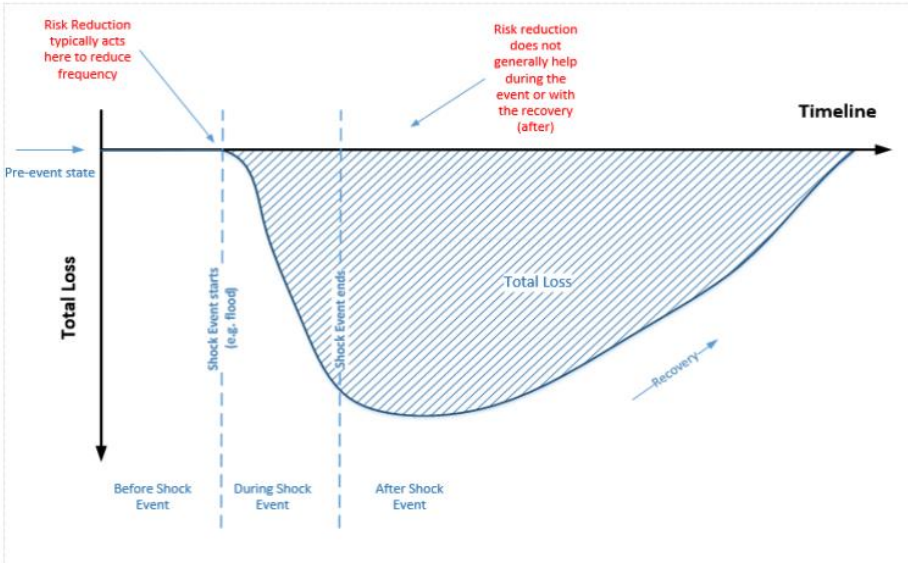


Figure 18: The risk reduction timeline from the HIT process

IV. Case Study: Common consequence tool for geotechnical asset management, Network Rail

Developed by	*Network Rail*
Sector	*Rail Infrastructure*
Applicable RSA Step(s)	*1*
STO	*Strategic, Tactical*
Suitability	*Red*
Ease of implementation	*Amber*

Overview

Network Rail has a huge and complex geotechnical asset base, which was mostly constructed before modern geotechnical understanding and practice. Failures amongst the 200,000 earthwork assets are relatively common. As a regulated industry, Network Rail is required to constantly improve their risk management processes and in 2016, they developed the common consequence tool for geotechnical assets.

Methodology

The common consequence tool consists of the following steps:

1. A risk-prioritisation matrix, including a quantitative likelihood of failure for all earthwork assets. These are generally assessed through visual inspection, and failure predictions are carried out using their 'Hazard Index', an algorithm which is optimised based on previous failure records.
2. Quantification of the consequences of earthwork failure. The consequences of train derailment (which are generally the most serious) are calculated using the Common Consequence Tool, which uses data such as typical train speed to estimate the probability of injuries and fatalities.
3. Development of earthwork intervention types and their effectiveness for preventing earthwork failure.
4. The development of a 'Whole Life Cost Decision Support Tool' to aid investment decisions for maintenance, refurbishment and renewal.

Analysis

The approach is extremely robust and helps to manage asset risks in an industry where fatalities and serious injuries are very rare. However, the tool does not take into account long-term stresses for resilience, such as increased storms due to climate change, which could put pressure on slope stability.

The tool's focus on the consequences of a failure rather than likelihood could be an approach Welsh Water could adopt in their Resilient Systems Approach as the likelihood of some shocks are difficult to quantify or lead to de-prioritisation of a risk for an asset that is 'too big to fail'.

Suitability for RSA

The aspects of this approach that could be applicable for Welsh Water are the quantification of the consequences of a failure, which uses typical data to estimate the probabilities of consequences and feeds into the risk prioritisation.

References

Power et al., 2016, Development of an Evidence-based Geotechnical Asset Management Policy for Network Rail, Great Britain, Advances in Transportation Geotechnics 3 . The 3rd International Conference on Transportation Geotechnics (ICTG 2016)

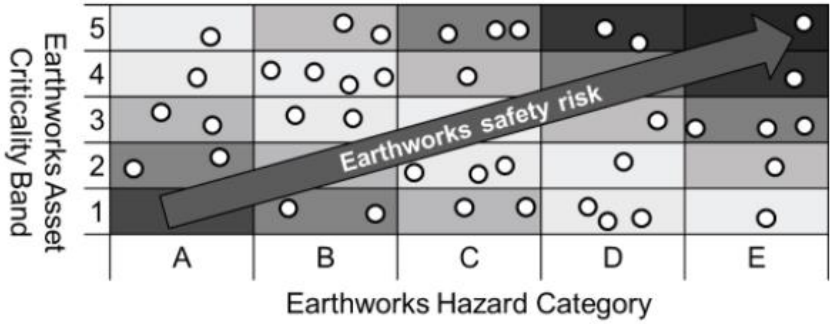


Figure 19: Network Rail's risk-based prioritisation matrix

V. Case Study: National Infrastructure Systems Model

Developed by	*ITRC-MISTRAL*
Sector	*Systems of systems*
Applicable RSA Step(s)	*None*
STO	*Strategic*
Suitability	*Red*
Ease of implementation	*Red*

Overview

NISMOD (National Infrastructure Systems MODel) is a prototype national infrastructure 'system-of-systems' modelling platform and database. As well as supporting investment decisions, the programme also aims to compare complex infrastructure systems at a national scale with those of other countries.

Methodology

Firstly, the system is geographically and spatially defined, and asset characteristics are entered into the system (including capacity, condition and age). Next, the present and future needs of infrastructure services inputted, such as per capita demand. Then, a long-term vision and strategic alternatives for delivering it are developed. Strategic alternatives are assessed in detail, including investment and policy options and key investment decisions points. Finally, adaptive pathways of policy and investment are recommended. The platform analyses interdependence and cross-sectoral demand, risks and vulnerability (including from natural hazards) and the impact of infrastructure on regional development.

Analysis

The model is the first attempt in the UK to create a complete model of the country's infrastructure and appears to have been effective at identifying key decisions points and feasible investment decisions.

Suitability for RSA

The model is primarily designed for multi-systems that have complex independencies at a national scale. Welsh Water's remit is only a small part of the total infrastructure asset base in England and Wales, so the tool itself may be of limited relevance.

References

Barr et al., 2013, A National Scale Infrastructure Database and Modelling Environment for the UK

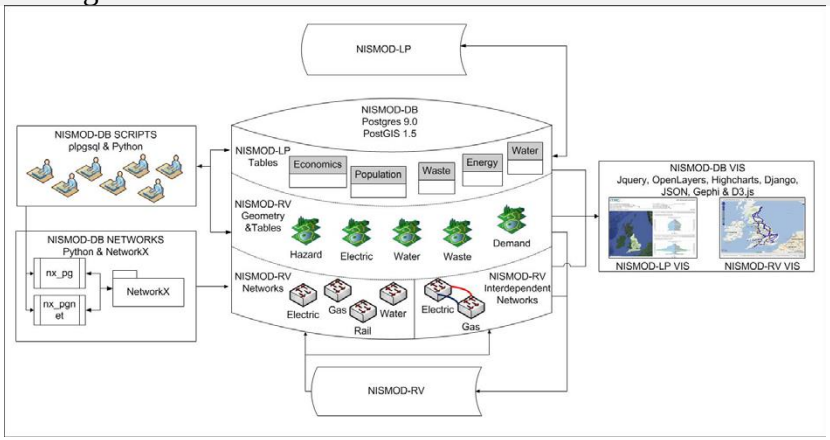


Figure 20: The overall organisation of the NISMOD spatial database, analysis and visualisation framework

VI. Case Study: The Future of Urban Water

Developed by	*Arup*
Sector	*Water*
Applicable RSA Step(s)	*1*
STO	*Strategic*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

'The Future of Urban Water: Scenarios for Water Utilities in 2040' (Arup, 2015) depicts four plausible scenarios for the future of urban water utilities in 2040. Using Sydney as a reference city, the report explores how a wide range of social, technological, economic, environmental and political trends could shape our urban water future. The aims of the exercise were to develop understanding of uncertainty, and improve conversations about the future and how we should plan for it.

Methodology

Drivers of change linked to the future of water utilities were identified at a global level. These drivers included global megatrends as well as sector-specific issues, and cover social, technological, economic, environmental and political elements.

Four scenarios were then developed; all had the same basic assumptions around development, urbanisation, climate change, volatility of supply, efficiency, and a shift to smart utilities. The differences between scenarios were based on two key variables – a centralised vs. decentralised system in terms of how utilities are operated; and separated vs. integrated utilities in terms of how different utilities co-operate across different types of infrastructure. Each of the four scenarios created by this matrix was then described in detail, and implications of each scenario on customers, infrastructure and governance were identified. A number of case studies for building resilient water utilities and urban water provisions were presented, with final conclusions around what resilient decisions look like in the face of the uncertainty provided by the different scenarios, and where further work should be focused.

Analysis

The study concluded that cities of the future will have to focus increasingly on local provision of water supplies, reuse and recycling to sustain themselves. It notes the important role of green infrastructure in stormwater management, as well as providing natural capital and amenity value to citizens. Shifting from water provision as a hidden service to a more visible service will help users value its key contribution to public life, and the report also notes that water utilities can shift to act increasingly as service providers for the development of autonomous systems, delivering integrated systems and making use of big data for optimising investments and influencing behaviour change.

Suitability for RSA

Aside from considering the conclusions of the work and their relevance to Welsh Water, a similar scenario-planning approach could be adopted by Welsh Water in the RSA process, identifying drivers of change and building potential future scenarios specific to the Welsh Water context to understand the compounding and cascading effects of shocks and stresses.

References

Arup, 2015, The Future of Urban Water: Scenarios for Urban Water Utilities in 2040

	Customers	Infrastructure	Governance	
	Focus on customer services that are user-centric and provide greater personal choice and control over service levels and pricing	Increased deployment of digital infrastructures and data analytics to manage, reduce or eliminate system peaks and fluctuating demand patterns	Higher levels of coopetition between water, energy and telecommunication companies with a focus on integrated planning and maintenance	Incremental Improvements
	Emphasis on creating a seamless customer experience across multiple integrated utilities, including shared billing, pricing and customer services	Integration and sharing of assets and infrastructure across multiple utilities, including water, energy, waste and telecommunications	Better cooperation between urban utilities through collaborative planning, integrated asset management, shared protocols and open data	Better Together
	Greater focus on services that enable customers to manage and maintain autonomous water systems at building, community or cluster level	Provision of planning and infrastructure services that enable communities to develop, run and maintain autonomous urban water systems	Governance and operation of autonomous systems and small-scale water networks through cooperatives, virtual networks and community platforms	Autonomous Communities
	Development of applications to provide customers with real-time data and information about water consumption, availability and pricing	Expansion of systems to manage and minimise the impact of extreme fluctuations in water availability, including fast shifts from too much water to too little	Implementation of differential water pricing and services according to availability of supply, service plans and customer behaviour	Survival of the Fittest

Figure 21: Future of Urban Water – implications across scenarios

VII. Case Study: Yorkshire Water Resilience Interdependencies

Developed by	*Yorkshire Water*
Sector	*Water*
Applicable RSA Step(s)	*1*
STO	*Strategic, Tactical*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

Yorkshire Water's approach to resilience takes key internal systems within the business and external systems that impact on our are impacted by Yorkshire Water's systems and assesses the interdependencies between the systems when shocks and stresses occur.

For each system, a resilience maturity assessment was undertaken taking into account the impact that the system had on external systems.

Using this approach, the business was able to select key areas of systems to improve.

Methodology

Yorkshire Water undertook a resilience maturity assessment based on the British Standards Institute standard for organisational resilience, considering 120 shocks and stresses. This assessment is planned to be embedded in the company's corporate risk approach, as shown in the flow chart below, during AMP7.

Yorkshire Water uses 5 qualities of resilience: resistance, reliability, redundancy, response and recovery and reflection.

As part of this approach, qualitative interdependencies mapping was undertaken for each of the 16 identified key systems. Using a matrix of influence based on academic research (Figure 23), this mapping identified the systems that depend on systems and are dependent on systems.

Analysis was also undertaken on mitigation and control measures to identify which external systems would benefit from resilience interventions.

Analysis

A key strength of this process is providing a clear evidence base behind interdependencies mapping. As it is a qualitative process, expert knowledge is required but significant background data is not needed.

Suitability for RSA

A similar process could be used in the RSA assessment to give an overview of the linkages between systems and indicate the link between shocks and stresses, systems and impacts.

A matrix of influence could be used to clearly identify how systems interact.

References

Yorkshire Water, 2018, Water Resilience in Yorkshire: The methodology and findings of our new framework to quantify the resilience of our business and services

Kunze et al., 2016, Applying Systems Thinking to City Logistics: A Qualitative (and Quantitative) Approach to Model Interdependencies of Decisions by various Stakeholders and their Impact on City Logistics, Transportation Research Procedia

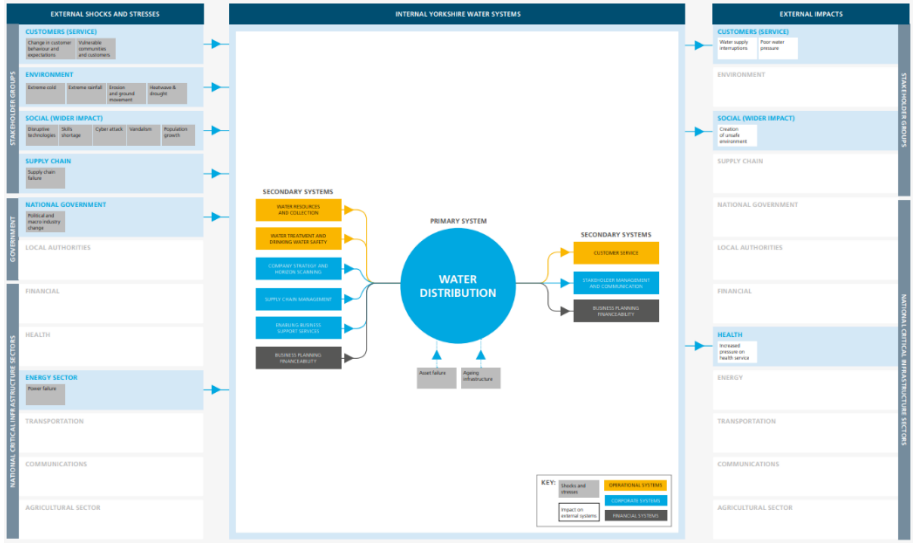
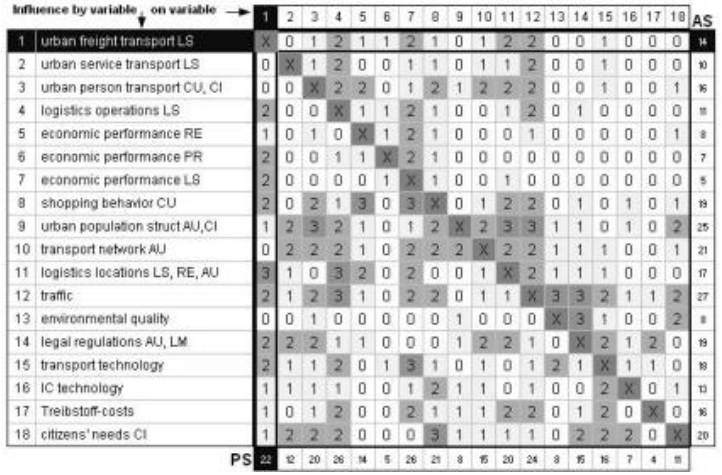


Figure 22: The Yorkshire Water PR19 interdependencies map



Influence by variable ↓ on variable →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	AS
1 urban freight transport LS	X	0	1	2	1	1	2	1	0	1	2	2	0	0	1	0	0	0	14
2 urban service transport LS	0	X	1	2	0	0	1	1	0	1	1	2	0	0	1	0	0	0	10
3 urban person transport CU, CI	0	0	X	2	2	0	1	2	1	2	2	2	0	0	1	0	0	1	16
4 logistics operations LS	2	0	0	X	1	1	2	1	0	0	1	2	0	1	0	0	0	0	11
5 economic performance RE	1	0	1	0	X	1	2	1	0	0	0	1	0	0	0	0	0	1	8
6 economic performance PR	2	0	0	1	1	X	2	1	0	0	0	0	0	0	0	0	0	0	7
7 economic performance LS	2	0	0	0	0	1	X	1	0	0	1	0	0	0	0	0	0	0	5
8 shopping behavior CU	2	0	2	1	3	0	3	X	0	1	2	2	0	1	0	1	0	1	19
9 urban population struct AU,CI	1	2	3	2	1	0	1	2	X	2	3	3	1	1	0	1	0	2	25
10 transport network AU	0	2	2	2	1	0	2	2	2	X	2	2	1	1	1	0	0	1	21
11 logistics locations LS, RE, AU	3	1	0	3	2	0	2	0	0	1	X	2	1	1	1	0	0	0	17
12 traffic	2	1	2	3	1	0	2	2	0	1	1	X	3	3	2	1	1	2	27
13 environmental quality	0	0	1	0	0	0	0	0	1	0	0	0	X	3	1	0	0	2	8
14 legal regulations AU, LM	2	2	2	1	1	0	0	0	1	2	2	1	0	X	2	1	2	0	19
15 transport technology	2	1	1	2	0	1	3	1	0	1	0	1	2	1	X	1	1	0	18
16 IC technology	1	1	1	1	0	0	1	2	1	1	0	1	0	0	2	X	0	1	13
17 Treibstoff-costs	1	0	1	2	0	0	2	1	1	1	2	2	0	1	2	0	X	0	16
18 citizens' needs CI	1	2	2	2	0	0	0	3	1	1	1	1	0	2	2	2	0	X	20
PS	22	12	20	26	14	5	26	21	8	15	20	24	8	15	16	7	4	11	

Figure 23: Matrix of influence taken from Kunze et al 2016.

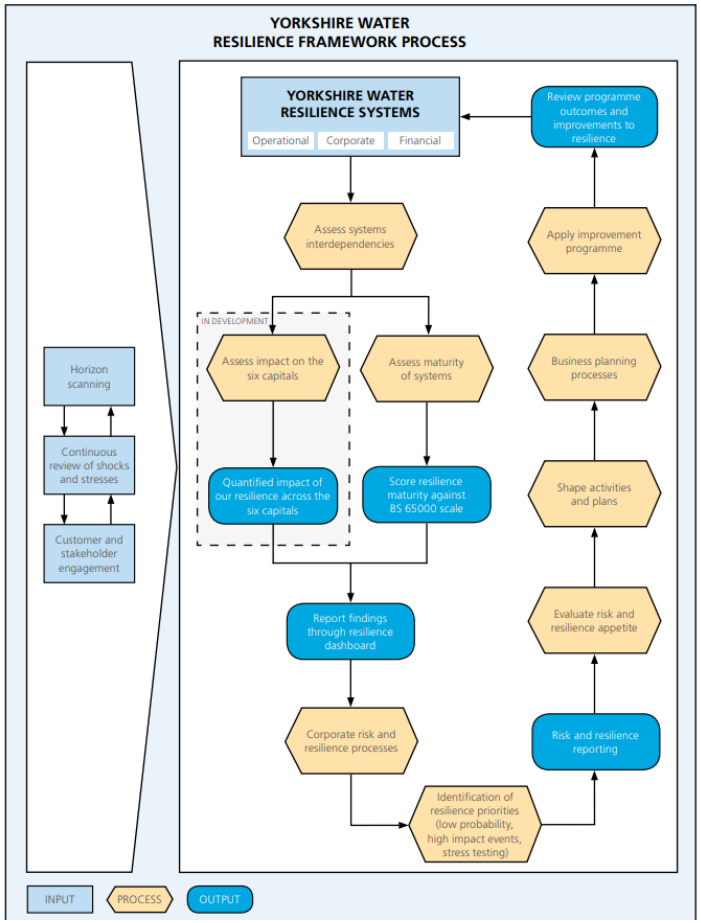


Figure 24: The Yorkshire Water Resilience Framework Process

VIII. Case Study: Earth Ex simulation

Developed by	*Electric Infrastructure Security (EIS) Council*
Sector	*Strategy*
Applicable RSA Step(s)	*1*
STO	*Strategic*
Suitability	*Amber*
Ease of implementation	*Amber*

Overview

Earth Ex is an acronym that stands for 'Emergency All-sector Response Transnational Hazard Exercise'. It is a series of annual cross-sectoral events involving media-enhanced exercises sponsored by the Electric Infrastructure Security (EIS) Council. Earth Ex is designed to evaluate resilience plans across sectors and nations, with a particular focus on six 'black sky' hazards (Figure 25) that represent particularly serious concerns from a system interdependency resilience perspective. It is designed to enhance public/private sector partnerships in preparing for response, restoration, sustainment and recovery in Black Sky events and complex catastrophes.

Earth Ex is in its third year of running, and in 2018 included 200 individuals and families as participants, from the recognition that resilience in the context of black sky hazards is not just dependent on government and corporations' responses but is also important at a community and individual level.

Methodology

Earth X gathers together a variety of participants from all backgrounds to take part in one or more exercises that simulate a 'black sky' hazard in order to test and develop multi-sectoral, cross-border responses in as realistic and immersive an environment as possible.

The exact nature of the simulated event may change from year to year; in 2018 it was a subcontinent-scale, long duration power outage, with cascading failures into all other infrastructures. The format was as a dynamic, multi-phase exercise lasting four hours, delivered world-wide via internet in the working hours of all time zones.

The format was designed to include two 90 minute, replayable dynamic exercise phases representing different aspects of the response and recovery timeline.
The media inputs included a video-based framing scenario, with sector-specific injects for each exercise 'lane', developed by key stakeholders in that sector.

Analysis

Whilst a simulated scenario can never completely reflect all of the intricacies of real-life impacts of such hazards, this type of exercise is one way of including as much realism as possible.
The focus on encouraging participation across the widest set of organisations, governments and individuals ensures a realistic set of interdependent systems are reflected.

Participants are not required to prepare ahead, which reduces barriers to participation and also increases realism.
This type of exercise is one way to really identify and begin to incorporate system interdependencies and the consequence of cascading failures in any resilience building work.

Suitability for RSA

A scaled version of the Earth Ex event focused on the key interdependencies and potential black sky hazards/cascading failures faced by Welsh Water would be a useful exercise in risk identification and prioritisation, helping to move the organisation beyond single risk identification and consequence mapping for a single system and towards the systems-based approach they have begun to develop. The Earth Ex style exercise could be done as a 'what-if' workshop to inform or complement the system interdependency mapping and scenario planning.

References

EIS Council, 2019, The second annual Emergency All-sector Response Transnational Hazard Exercise, https://www.eiscouncil.org/newsItem.aspx?itemId=10074&sysId=1 , Accessed on: 29/05/2019

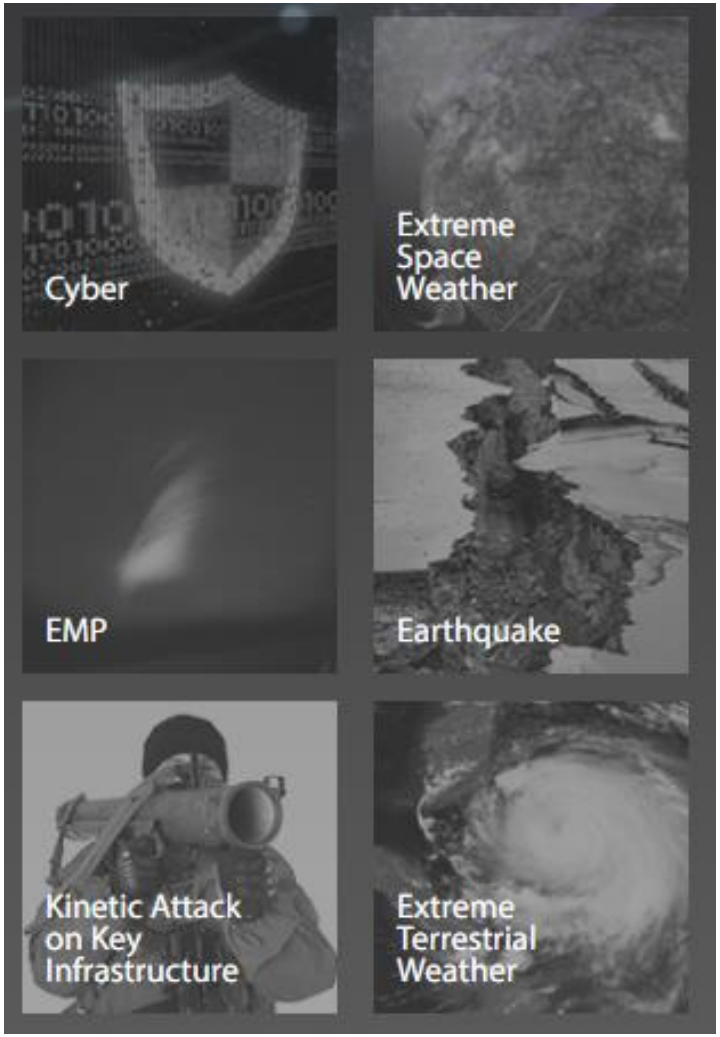


Figure 25: Six key 'black sky' hazards that the Earth Ex event focuses on simulating and testing responses towards.

IX. Case Study: Lifelines Council interdependencies approach

Developed by	*The City and County of San Francisco*
Sector	*Local Government*
Applicable RSA Step(s)	*1*
STO	*Strategic, Tactical*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

The Lifelines Council, a city wide post-disaster resilience and recovery initiative created in San Francisco, undertook an interdependency study. This aimed to understand key systems (or lifeline systems) performance and interdependencies to support the planning response.

Methodology

The study identified 11 lifeline operators, managing 12 types of lifeline systems. The modelling was undertaken for a scenario similar to a repeat of the 1906 San Francisco earthquake and the resulting impact on the population, businesses, regional roads, city streets, electric power, natural gas, telecom, water, auxiliary water, wastewater, transit, port, airport and fuel (each assessed by the amount of disruption caused).

As part of the analysis each of these systems were assessed for timeframes for restoration. The matrix of interdependencies is shown as a figure in the case study.

Interdependencies are split into types of interdependencies:

- Functional: disaster propagation and cascading interactions from one system to another due to interdependence
- Collocation: interaction, physical disaster propagation among lifeline systems
- Restoration: interaction, various hindrances in the restoration and recovery stages
- Substitute: interaction, one system's disruption influences dependencies on alternative systems
- General: interaction between components of the same system.

There is also some consideration of how key systems interaction with management structures (national, region, city, internal organisation).

Analysis

This report included a recommendation that the city should consider 'choke points' where vulnerability, disruptions and interdependencies are more concentrated.

Suitability for RSA

The use of the system interdependency matrix and dependency lines could be an interesting method to use for Step 1: Risk Prioritisation, for the system interdependency mapping.

References

The Lifelines Council (The City and County of San Francisco), 2014, Lifelines Interdependency Study I Report.

The overall interaction and dependency on a particular system (read down each column)

Lifeline operators' dependency on other lifeline systems (read across each row)

	Regional Roads	City Streets	Electric Power	Natural Gas	Telecom	Water	Auxiliary Water	Waste-water	Transit	Port	Airport	Fuel
Regional Roads	General	Restoration Substitute	Restoration	Restoration	Restoration	Restoration		Restoration	Substitute		Restoration	Restoration
City Streets	Substitute, Restoration	General	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Substitute, Restoration	Collocation, Restoration		Restoration
Electric Power	Restoration	Collocation, Restoration	General		Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration		Collocation	Restoration	Restoration
Natural Gas	Restoration	Functional, Collocation, Restoration	Substitute	General	Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration		Collocation	Restoration	Restoration
Telecom	Restoration	Collocation, Restoration	Functional, Restoration	Restoration	General	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration			Restoration	Restoration
Water	Restoration	Restoration	Restoration		Restoration	General				Collocation		Restoration
Auxiliary Water	Restoration	Functional, Restoration	Restoration		Restoration	Functional, Restoration	General			Collocation, Restoration		Restoration
Waste-water	Restoration	Collocation, Restoration	Functional, Restoration		Restoration	Functional, Restoration		General		Collocation, Restoration		Restoration
Transit	Substitute, Restoration	Functional, Substitute, Collocation, Restoration	Functional, Restoration		Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, General	Collocation, Restoration		Functional, Restoration
Port	Restoration	Collocation, Restoration	Collocation, Restoration		Collocation, Restoration	Collocation, Restoration	Collocation	Collocation	Collocation	General		Restoration
Airport	Restoration		Restoration		Restoration	Restoration		Restoration	Collocation, Restoration		General	Functional, Restoration
Fuel	Restoration	Restoration	Functional, Restoration		Restoration	Restoration				Restoration	Restoration	General

Figure 26: System interdependencies following the potential scenario. Darkest blue shows significant interaction and dependency on this lifeline for service delivery and restoration efforts, middle blue signifies moderate interaction and dependency and light blue signifies limited interaction and dependencies.

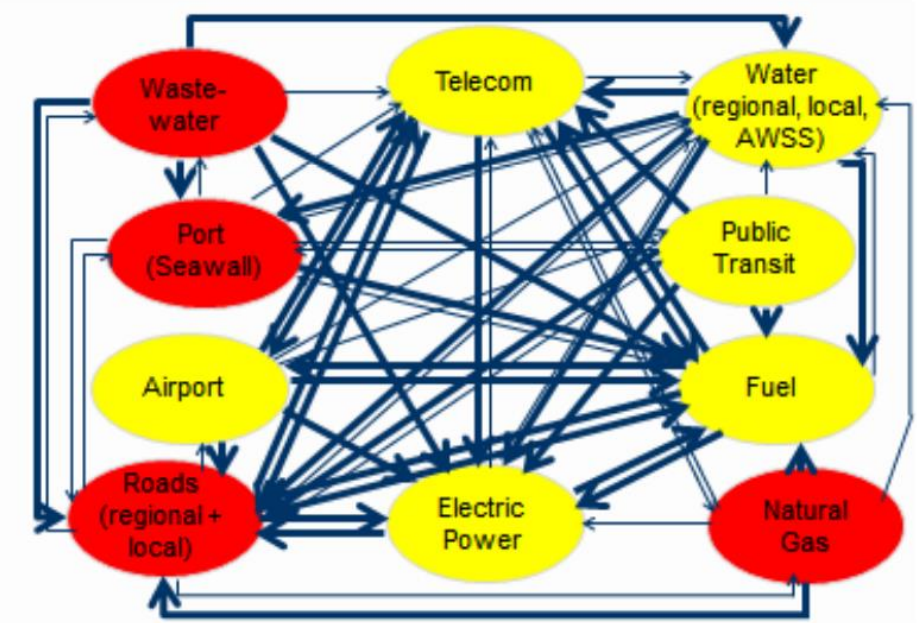


Figure 27: Combined effect of damage, service disruption and may cause delays in individual system restoration and interdependencies between systems. Colour of systems relates to overall level of system disruption (red: severe, yellow: moderate, green: slight), and the lines show dependency, with the thickness of the line highlighting the level of dependency.

X. Case Study: Ministry of Defence Global Strategic Trends

Developed by	*Ministry of Defence (UK)*
Sector	*Defence Strategy*
Applicable RSA Step(s)	*1*
STO	*Strategic*
Suitability	*Amber*
Ease of implementation	*Green*

Overview

Global Strategic Trends is a method for identifying and creating scenarios for phenomena which potentially could have a significant impact on the future. It is a tool intended to be used for developing long term plans, policies and capabilities, and is regularly updated, currently on its fifth edition.

Methodology

The first step in the approach is to identify and define trends through a review of previous data. The trends are then projected forward 30 years to analyse their consequences in order to define key scenarios. Policies and plans are then tested against the projected scenarios to determine the alternative outcomes.

Thirteen clusters of trends were defined, along with connections and inter-dependencies between these trends. Economics, religion, technology and globalisation are considered across all of the trends. The thirteen scenarios have been applied across eight geographical regions, along with low probability disruptor events or ‘shocks’.

Analysis

Some of the scenarios could be useful to Welsh Water in understanding the future scenarios that Welsh Water may face.

Suitability for RSA

Both the approach and outcomes of the Global Strategic Trends study could be adapted for the Welsh Water Resilient Systems Approach. The approach could be used if Welsh Water wish to create their own scenarios and the outcomes could be used if Welsh Water wish to align with the Ministry of Defence scenarios.

References

Ministry of Defence (UK), 2018, Global Strategic Trends: The future starts today (sixth edition)

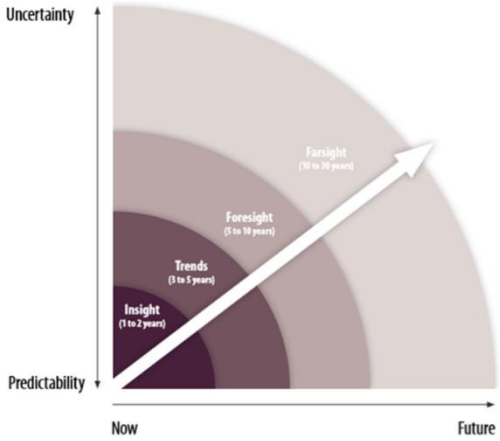


Figure 28: Timeframe looking out 30 years. Strategic Trends Programme. Global Strategic Trends – Out to 2045. 5th Ed.

XI. Case Study: Monte Carlo analysis

Developed by	*Not applicable*
Sector	*Modelling and statistics*
Applicable RSA Step(s)	*1*
STO	*Strategic*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

Monte Carlo analysis is a computer simulation technique that constructs probability distributions of the possible outcomes of various decisions, allowing for a quantitative assessment of the level of risk that comes with taking a particular decision. The decision maker can then choose what action to take to balance benefit against risk.

Methodology

The method for Monte Carlo analysis is based around a mathematical model which allows for hundreds or thousands of model runs, each time selecting inputs at random from the range of possibilities, and recording every output to generate the probability distribution.

Analysis

Monte Carlo analysis is often included within other broader methods as a component part in developing scenarios and likelihood/probabilities as part of risk identification and quantification.

Suitability for RSA

Welsh Water could integrate Monte Carlo analysis into its RSA as a component of risk identification and quantification, but it should be part of a suite of tools that also bring in other, non-mathematical or less quantitative methods of assessment to ensure all aspects of resilience are considered.

References

Blos et al., 2008, Unpredictability of Supply Chain Risks: An alternative approach of managing costs

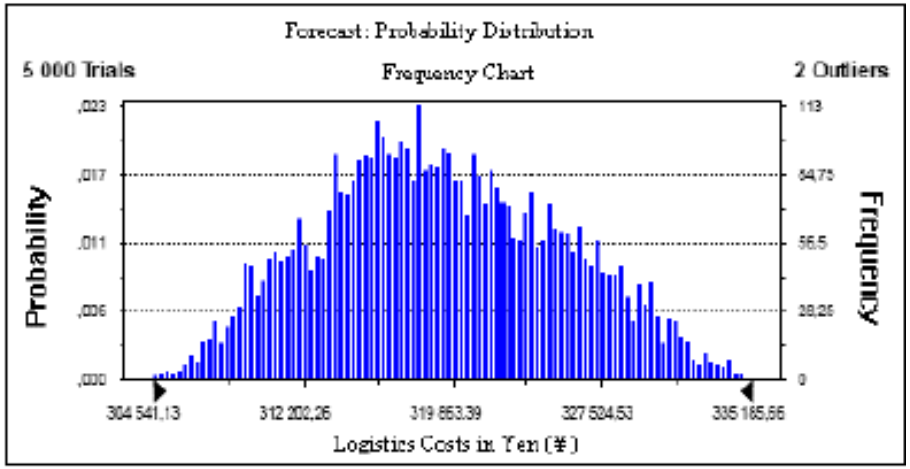


Figure 29: A probability distribution from using Monte Carlo simulation

XII. Case Study: Bristol Resilience Strategy scenario planning

Developed by	*Bristol City Council & Arup*
Sector	*Local Government*
Applicable RSA Step(s)	*1*
STO	*Strategic*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

The City of Bristol published its resilience strategy in 2016 as part of the 100 Resilient Cities (100RC) programme. It used scenario planning to support this work, particularly in relation to horizon scanning, with four selected resilience scenarios out to 2066.

Methodology

To build the scenarios, two future trends are selected and placed orthogonal axes. Each of the four quadrants formed by the intersection of these variables can be considered as contrasting but credible future scenarios, against which decisions and policies can be tested.

The axes chosen by Bristol were climate change impact, and societal wellbeing, describing four futures as follows:

- Thrive & survive: high climate change impact and high societal wellbeing.
- Survival of the fittest: high climate change impact and low societal wellbeing.
- Regulated carbon: low climate change impact and low societal wellbeing.
- Green & smart: low climate change impact and high societal wellbeing.

By testing decisions against the variable futures, it can help decision makers to select responses that will improve resilience and develop a more nuanced, flexible response.

Bristol chose to analyse different options under each scenario through a method known as ‘wind tunnelling’, to test the relevance, practicality and implementation of policies under each scenario.

Analysis

Using scenario planning as a policy analysis or decision-making tool can be very helpful with regards to ensuring that decisions help to build, not erode resilience.

Suitability for RSA

Welsh Water could undertake a similar exercise to develop scenarios during workshops that inform strategic and tactical levels of decision-making to improve resilience.

References

100 Resilient Cities, 2016, Bristol Resilience Strategy

Figure 30: The four scenarios developed for Bristol's 100RC City Resilience work.

XIII. Case Study: South West Water and SIM4NEXUS

Developed by	*South West Water*
Sector	*Water*
Applicable RSA Step(s)	*1*
STO	*Strategic*
Suitability	*Amber*
Ease of implementation	*Red*

Overview

South West Water have developed a method of cross-sector modelling with the EU funded research project SIM4NEXUS, which takes a systems-thinking approach to understanding interrelationships.

Methodology

NEXUS is an academic approach to modelling for assessing various policies. It uses Complexity Science models to develop the overarching System Dynamics Model (SIM). It considers a demand led approach to meet societal demands and looks beyond the company's operations to the wider context and market. The developers are converting these models into an interactive 'Serious Game, to engage with customers and stakeholders. This allows policy makers to play out different scenarios in the short, medium and long term.

The model considers three key components of resilience: avoiding losses, stimulating economic activity, and the development of co-benefits. The model provides an opportunity to test a range of scenarios over different modules which are water, land, food and energy (the nexus).
It breaks down problems into sub-systems and sub-models and uses existing macroeconomic energy knowledge models (e.g. E3ME) to consider different types of drivers including legal, political, business and financial to support decision making.

Analysis

South West Water plan to test the 'Serious Game' for land use management policies to collaborate with farmers to change the way they manage land in the face of climate change.

Suitability for RSA

Step 1: System mapping, scenario development
The SIM4NEXUS approach is an academic methodology to assess the interdependencies between a water company and wider market drivers. The interdependencies identified by the SIM4NEXUS approach could inform the Welsh Water system interdependencies mapping.
Step 2: Development and prioritisation of mitigation options
The use of these models as an interactive 'Serious Game' to engage stakeholders and customers on possible mitigation options is a potential course of action to consider in the future, when the RSA has been developed and tested.

References

South West Water, 2018, Securing Long-Term Resilience

Brouwer et al., 2018, The Nexus Concept Integrating Energy and Resource Efficiency for Policy Assessments: A Comparative Approach from Three Cases

SIM4NEXUS, 2019, Serious Game, http://seriousgame.sim4nexus.eu/https://www.eiscouncil.org/newsItem.aspx?itemId=10074&sysId=1 , Accessed on: 29/05/2019

SIM4NEXUS, 2019, SIM4NEXUS South West UK Case Study, https://www.sim4nexus.eu/page.php?wert=Casestudies&id=Southwest , Accessed on: 29/05/2019

Figure 31: 'Serious Game' geo-spatial policy impact visualisation

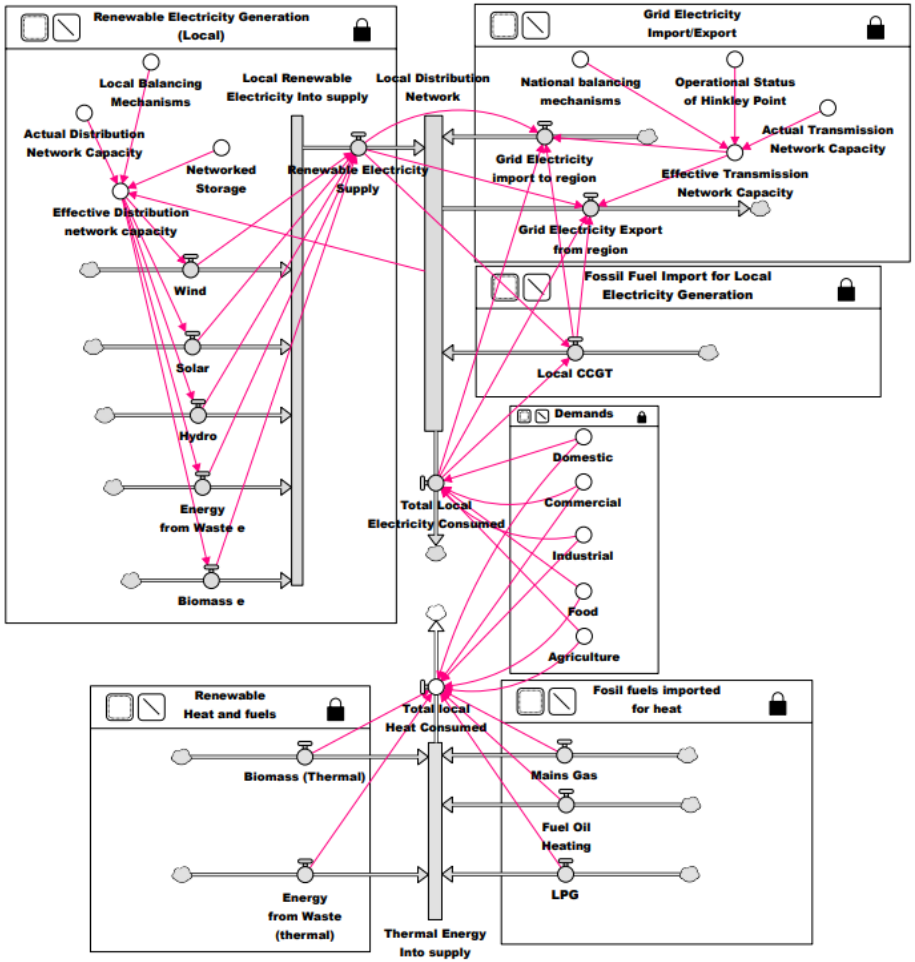


Figure 32: The NEXUS model for the energy sector in the Southwest UK

XIV. Case Study: UKWIR WRMP Risk Based Planning and Decision Making

Developed by	*UKWIR*
Sector	*Water*
Applicable RSA Step(s)	*1,2*
STO	*Strategic, Tactical*
Suitability	*Amber*
Ease of implementation	*Amber*

Overview

This process is a new approach developed by UKWIR, focusing on problem characterization, risk composition and integration methods. It supports water companies' planning and decision making specifically in relation to developing Water Resources Management Plans (WRMPs).

Methodology

There is a six step process for this risk-based planning approach, shown as a process diagram below.

Step 1: Problem characterisation: is used for assessing a company's vulnerability to various strategic risks and uncertainties (risk composition, 'complexity factors' and component inputs). This process includes:

- **Scenario simulation and robust decision making (RDM)**: This method is most likely to be used by companies where there is a good understanding of likely preferred portfolios but want to robustness test of portfolio at a specific time in the future. This method does not create schedules of investment, but tests those already created at a specific point in time.
- **Portfolio risk simulation (PRS)**: This method is used when a more detailed development of future scenarios is required. It provides an objective ranking-based assessment on which proposed schedules must satisfy identified risk criteria. This approach only helps to select between a number of predetermined schedules. It also requires a number of runs to generate risk profiles meaning the number of profiles for testing may be limited. To undertake the process expert judgment is needed to choose the best option.
- **Infogap analysis**: This method identifies how much future variability can be tolerated before threshold of failure. It only tests a set point in time in the future but can be used to test 'tipping points'.
- **Multi-criteria search (MCS):** One of the most accessible tools which generates preferred portfolios from individual options. It can therefore be used to show the creation of a range of portfolios that address a risk. However, it only produces a portfolio of outputs at a specific point in time. It can also test a limited range of scenarios (especially compared to RDM) as it is computationally intensive.
- **MSC with scheduling**: Similar to the MSC method, but it additionally indicates when schemes need to be timed to

provide optimal solutions. It provides a scheduled, optimized, fully automated approach to multiple planning objectives including system resilience metrics. However, it has a limited ability to look at a range of scenarios as large computational burden.

- **Adaptive pathways**: This method allows strategic flexibility and a high degree of coincidence in the tactical suitability of near term investments. There have been no issues highlighted as has not be used or tested for a WRMP before.

Step 2: has three risk compositions; one for business as usual, one for a resilience tested plan and a third for a fully risk-based plan. It is used to test the cost benefit trade-offs of different levels of future target.

Step 3: identifies integration methods to combine supply, demand and outage components. It uses either an aggregated approach (e.g. using a scenario-based method) or a system simulation approach.

Step 4: is a checking phase which is used to check the work undertaken in steps 1-3 is appropriate.

Step 5: includes the completion of the component reference card. This card includes: cost and complexity score, cost and time implications and levels of resources and expertise required for each option.

Step 6: is the calculation step which helps identify suitable decisions.

Analysis

This methodology was developed specifically for the purpose of developing WRMPs, so not all of the specific elements will be appropriate for general resilience approaches. However, this type of approach will increasingly be adopted in the water sector so is worth building on.

Suitability for RSA

Step 1: Risk Identification

This process gives the opportunity to use multiple tools to reach the same goal in the problem characterisation step, depending on the vulnerability identified.

Step 2: Development and prioritisation of mitigation options

This approach sets out a wider framework for risk based planning which can be drawn on, as could specific items such as the component referencing cards for mitigation options.

References

Hunt et al., 2015, WRMP 2019 Methods – Risk Based Planning

Baker et al., 2015, WRMP 2019 Methods – Decision Making Process: Guidance

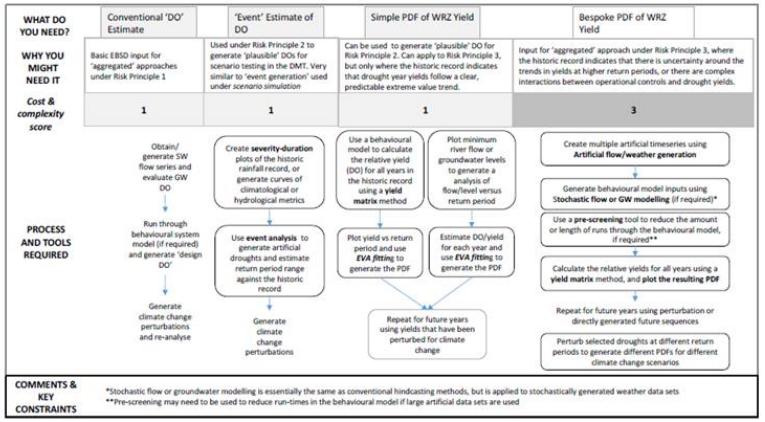


Figure 33: Component Reference Card from the Risk Based Planning Tool- example for supply side components

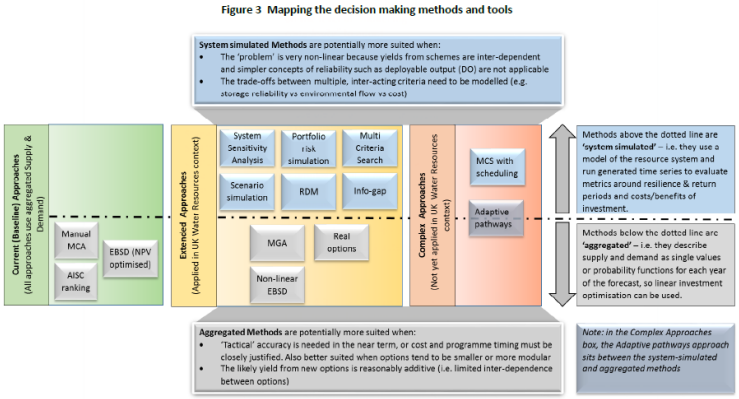


Figure 34: Mapping the decision-making methods and tools

Figure 35: Process used for generation WRMP inputs in risk based planning framework

Approach	Risk composition 1 (conventional)	Risk Composition 2 (event based)	Risk Composition 3 (fully risk based plans)
Scenario simulation/ robust decision making	Rating 1: Simple method- no more complex that conventional climate models.	Rating 2: Increased number of runs required, but not too difficult.	Rating 3: fairly complex. Need screens to reduce amounts of inputs.
Portfolio risk simulation	Rating 3: requires generation of multiple future scenarios	Rating 3: same s risk comp 1.	Rating 4: Very complex, needs complex sampling method to integrate inputs for tool
Infogap analysis	N/a	Rating 3- step wise approach to running a system simulator	n/a
System sensitivity analysis	n/a	Rating 3: large amounts of data management and multiple scenario ranges	N/a
Multi-criteria search	Rating 3: potentially challenging to set up and run to reflect the water system even with basic inputs	Rating 3: ditto Risk 1.	Rating 4: Very complex would need complex sampling methods to ingrate inputs
MSC with scheduling	Rating 4: Experimental methods- complex with basic inputs	Rating 4: Ditto Risk 1.	Rating 5: Very complex unknown requirements
Adaptive pathways	Rating 4: Experimental method- not yet fully determined for WRMP	Rating 4: Ditto Risk 1	Rating 5: Very complex unknown requirements
Real options analysis	Rating 2: Similar to existing method- adaptation of linear optimizer needed.	Rating 2: as Risk 1- with some additional scenarios added.	Rating 3: very likely to require integrated risk modelling to generate scenario probabilities.

Figure 36: The decision making framework for investment appraisal and optimisation

XV. Case Study: United Utilities resilience review

Developed by	*United Utilities*
Sector	*Water*
Applicable RSA Step(s)	*1,2*
STO	*Strategic, Tactical, Operational*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

United Utilities took a strategic, high-level approach to comprehensively review a number of water and wastewater approaches to building resilience. The review was focused on an asset site level and considered the current situation, identifying options to improve the situation and the prioritisation of where investment may be made. Part of the review involved an analysis of the criticality of each site, the impact and likelihood of failure, and identification of mitigation options. From this process, a prioritised list of key assets was then created along with mitigation costs and time periods to support investment decision making.

Methodology

The review used a prioritisation method of asset/ site specific risk-based investment. The data to feed into this process was largely qualitative information from 'what-if' workshops with the asset managers in the company, looking at the impacts of various shocks and stresses. The following information fed in to the assessment:

- Asset size and criticality,
- Resilience consideration,
- Event type and description (shock or stress impacting the site),
- Likelihood of failure using a matrix,
- Effect of that failure (Impact on third parties and the environment etc), and
- Coping impact (considering the 4 Rs, and time and costs).

The findings were combined to create an overarching score which was then used to prioritise mitigation options.

Analysis

A key strength is in the workshopping to bring out key details for each site. This methodology was able to consider shocks and stresses for a large number of sites (123 sites). It focused on the impact of failure as the key focus, likelihood was only used to input into prioritisation where two assets got the same prioritised score.

Suitability for RSA

Step 1. Risk identification and prioritisation
A similar method of identification of impact could be adapted to be used in the RSA, which focuses on impact rather than likelihood.
Step 2. Development and prioritisation of mitigation options
This could be used to prioritise a number of mitigation options to identify those that provide the most benefit for third parties and the environment.

References

Arup, 2017, United Utilities Resilience Support
Arup, 2017, United Utilities Waste Water Resilience Support

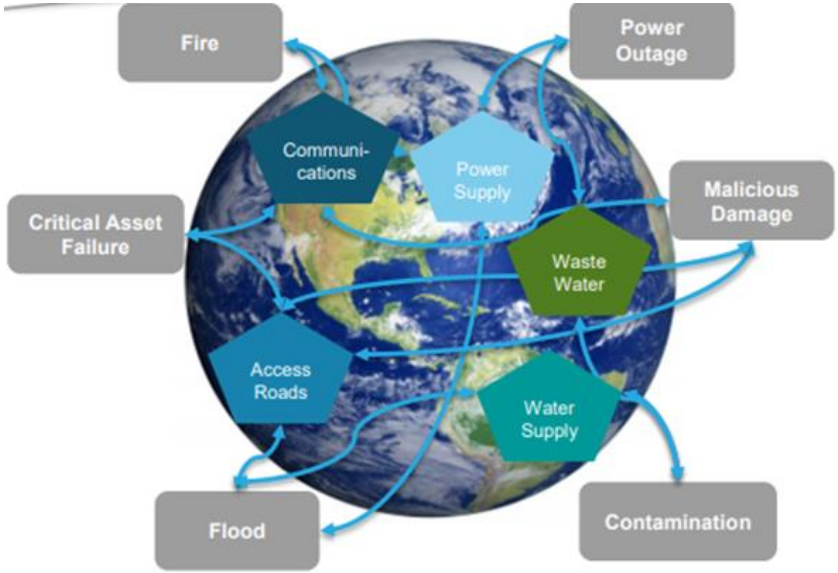


Figure 37: Interdependencies from the Unities Utilities report.

XVI. Case Study: Factor Mapping

Developed by	*George Fox University, University of Boulder, Colorado*
Sector	*International Development*
Applicable RSA Step(s)	*1,2*
STO	*Strategic, Tactical*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

Factor Mapping is a qualitative, collaborative approach to targeting interventions or investments. Any given systems will have 'factors' which represent tangible (e.g. hard infrastructure) or intangible (e.g. community participation) elements of that system. The desired outcome of a scheme, and the extent to which it is being achieved, is also a factor and is itself dependent on other factors. Factor mapping is a collaborative method that helps to identify those factors in a complex system which have the most influence on the desired outcome (known as 'leverage points'). The process can be used to help a business to make investment decisions.

Methodology

As part of a factor mapping exercise, stakeholders agree on a system boundary, and an appropriate list of factors that have some relationship to a particular outcome. Pairwise comparisons are then made of *every* factor, and a quantified score (typically 1-5) is given as to the strength of the relationship between each factor, or the extent to which one influences the other. All the factors can then be plotted on a graph, based on their level of influence on the outcome factor, and level of dependence on other factors. This then helps organisations to target factors than have most influence on the desired outcome, and monitor factors that are highly sensitive to others and those that can lead to volatile outcomes.

Analysis

The methodology has been used by academic institutions to help target the interventions of development projects. It can be useful in distilling the complexity of a project where a desired outcome is dependent on multiple different factors. It is used in the international development sector.

Suitability for RSA

Step 1: System Interdependencies
A similar process could be used in the RSA assessment to give an overview of the linkages between systems and indicate the link between shocks and stresses, systems and impacts.
Step 2: Development and prioritisation of mitigation options
Many of Welsh Water's service measures are dependent on many tangible and intangible factors. The implementation of factor mapping

as part of a Resilient Systems Approach could support the targeting of investments and lead to more resilient outcomes.

Reference

IRC, ‘Leaving no one behind’, IRC Symposium ‘All systems go’ 12-14 March 2019.

Figure 38: A typical factor mapping exercise

XVII. Case Study: HAZUR Tool

Developed by	*Opticits*
Sector	*Local Government*
Applicable RSA Step(s)	*1*
STO	*Strategic*
Suitability	*Amber*
Ease of implementation	*Amber*

Overview

The tool supports city decisions makers to improve resilience based on interconnections among services. It includes background material on resilience thinking, an assessment to support investment planning and strategy making, and a manager tool to simulate the impact of risks on a city. The tool analyses interdependencies between services and infrastructure, redundancy and cascade effects.

Methodology

HAZUR is a piece of software designed to support the design, implementation and management of cities resilience strategy. The HAZUR approach is composed of 2 modules: HAZUR Assessment and HAZUR Management.

1. HAZUR Basic is the online software included in the certification courses of the Resilience Academy. It includes the basic functionalities to build your own city project.

2. HAZUR Assessment helps to summarise all city data, to analyse interdependencies in service networks, to assess impacts aftermaths and cascade effects. It also enables the identification and prioritisation of potential improvement project, facilitates the definition of crisis management protocols and supports a strategy development process.

3. HAZUR Manager combines the Assessment information with real-time information and enable the simulation of risk situations at city level. It also equips the cities and experts with tools for service network monitoring, risk management and city stakeholder coordination.

Analysis

We have not seen any examples of the application of HAZUR to a real world situation, however the overview of the method seems useful, albeit city-focused.

Suitability for RSA

This tool may be less useful to Welsh Water as it is focused on city-scale design and implementation of resilience building actions. The same principles could be applied to welsh water specific circumstances but may require modification. This could be applied in the second stage, prioritisation of mitigation options.

References

Opticits, 2019, HAZUR Web Tool, http://opticits.com/, Accessed on: 29/05/2019

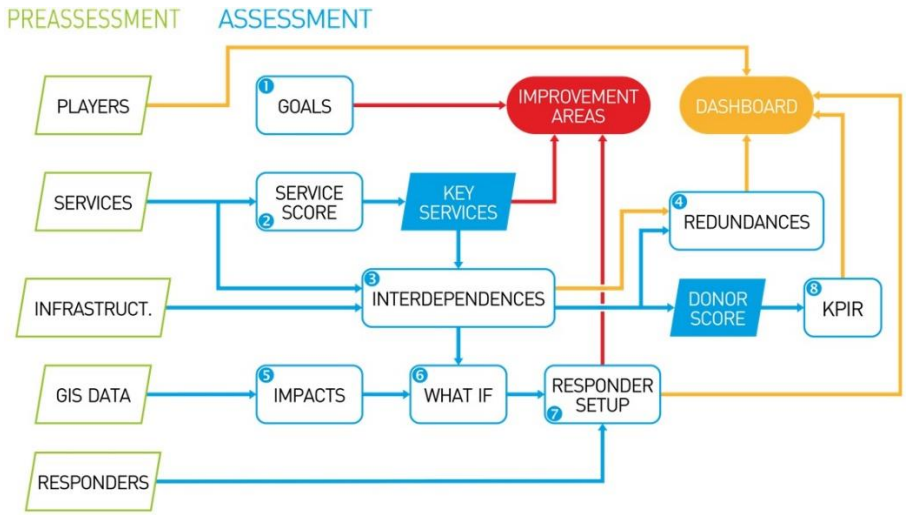


Figure 39: Image/diagram 1

XVIII. Case Study: BSI City Resilience

Developed by	*British Standards Institute*
Sector	*Local government and city stakeholders*
Applicable RSA Step(s)	*1*
STO	*Strategic*
Suitability	*Amber*
Ease of implementation	*Amber*

Overview

This is a recently published British Standard for resilience to provide practical guidance and tools to for city stakeholders to work together to improve resilience. It partly aims to build integrated capacity in the city and to strengthen investment decisions.

Methodology

The BSI on City Resilience has created a framework to assess and develop city resilience. As part of this process, it has created a five-step process of creating resilience. These steps are:

- *Organise and define*: This step includes stakeholder and citizen engagement, development of vision, leadership and governance.
- *Assess and prioritize*: This step involves identifying and assessing shocks and stresses, looking at the city's systems understanding including a view of their value chains and a gap analysis.
- *Plan and prepare*: This step includes the preparation of a resilience strategy option development and choosing the best option.
- *Partner and deliver*: This step includes delivering the programme as well as identifying partnerships and enablers.
- *Continuously improve*: includes learning from experience, reporting, and monitoring.

For each step of this process there is a qualitative evaluation process assessing each step for qualities of resilience. These qualities are integrated, inclusive, durable, reflective and adaptive.

It includes suggested tools and methodologies that could be used to assess interdependencies. BSI suggests the CARVER tools for food sector vulnerability, which creates a qualitative score (from 1-10) for the following aspects:

- Criticality- the measure of public health and economic impacts,
- Accessibility- the ability to physically access and egress,
- Recuperability- the ability of a system to recover from an attack,
- Vulnerability- the ease of accomplishing attack,
- Effect- the amount of direct loss from an attack as measured by loss in production, and
- Recognizability- the ease of identifying target.

The BSI on city resilience also suggests the method used for the interdependency matrix for energy and communications, which details High Centrality Interdependency Matrix, Low Centrality Interdependency Matrix. In this paper the Average Two-Terminal Reliability (ATTR) robustness metric is used.

$$ATTR = \frac{\sum_{i=1}^{c} K_i(K_i - 1)}{N(N-1)}$$

This metric is detailed aboved where c= number of components, K_i= the number of nodes in component i, and N= the number of nodes in the network. This approach suggests the that the best tool to use for choosing options is the multi-criteria analysis, from the UK government manual.

Analysis

This is high level qualitative guidance for cities, which evaluates resilience based on its five qualities of resilience.
It also directs to some in-depth tools that could be useful to learn from. It is a recently published standard so it applicability in practice has yet to be tested.

Suitability for RSA

The approach taken to use the qualities of resilience as a method for evaluation is an interesting one that could be used in the options prioritisation section of the RSA.
The interdependency tools identified are interesting potential approaches to consider in step 1- looking at system interdependencies

References

U.S. Food and Drug Administration, 2009, Carver + Shock Primer. An overview of the Carver Plus shock method for food sector vulnerability assessments

Rueda et al., 2017, Using interdependency matrices to mitigate targeted attacks on interdependent networks: A case study involving a power grid and backbone telecommunications networks

HM Treasury (UK), 2013, Green Book supplementary guidance: multi-criteria decision analysis

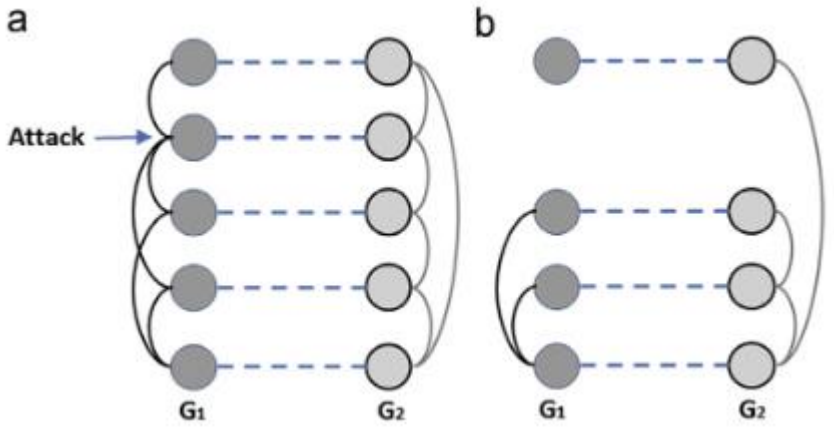


Figure 40: targeted attacks on interdependent networks- in this case each node in G1 relies on only one node in G2. In Fig. 1(a),one node inG1is attacked based on its centrality measure. In Fig. 1(b), only the dependent node inG2is removed (Rueda & Calle 2017).

XIX. Case Study: Real Options Analysis

Developed by	*Industry*
Sector	*Multiple sectors*
Applicable RSA Step(s)	*2*
STO	*Strategic, Tactical, Operational*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

Real Options Analysis (ROA) is a method that takes account of the inherent value of uncertainty and flexibility instead of assuming a specific or certain future for any Cost Benefit Analysis. ROA has been in use since the 1960s by energy firms, chemical industry and pharmaceutical companies for phased investments, growth planning and R&D decisions.

Methodology

In ROA flexibility has a value, in that it allows one to limit the downside of making a wrong decision as well as capturing the upside of new information and opportunities. This is a heuristic method– a rule of thumb allowing for flexibility and quicker decision-making in a complex, ever-changing environment. ROA is based on logical financial choices and recognises that those financial options create a certain amount of valuable flexibility. Real options can be grouped according to those ‘in’ a system (i.e. options that are built into the design of a system such as plans for future expansion), and those options ‘on’ a system (generally the financial and managerial options of a project such as deferring a project or swapping to another project). Most commonly calculated with a Monte Carlo Analysis and decision trees, ROA can enhance adaptive pathways by establishing the economic value created by flexibility, rather than merely comparing cost and benefits from individual paths, which fails to recognise this economic value.

Analysis

The value (benefits) of flexibility can be compared against costs required to incorporate the required degree of flexibility. It focuses on the importance of timing not just value. It is most appropriate when the environment and market conditions are highly volatile and flexible. ROA is applicable only when a firm's corporate strategy lends itself to flexibility, has sufficient information flow and has sufficient funds to cover potential downside risks associated with real options. The merits of using Real Options Analysis is that it provides a manner to objectively (within the limitations of quantification of costs, benefits and uncertainty) compare options and provide a valid argument to incorporate flexibility. This often leads to higher investment costs and increased design complexity, meaning ROA is not always popular as a method – critics state that ROA overestimates the value of uncertain projects and is too much based on assumption. Real Options Analysis provides a different perspective on uncertainties: uncertainties cannot be avoided but could be re-cast to present valuable opportunities.

Suitability for RSA

Step 2. Development and prioritisation of mitigation options
This can be used instead of a cost benefit analysis at the optioneering stage to provide a robust method to make uncertainties become valuable opportunities for development.

References

Buurman er t al., 2017, Adaptation Pathways and Real Options Analysis: An approach to deep uncertainty in climate change adaptation policies, Policy and Society

van Putten et al., 2004, Making Real Options Really Work, https://hbr.org/2004/12/making-real-options-really-work Accessed on: 29/05/2019

XX. Case Study: A customer-focused framework for electricity system resilience

Developed by	*Natural Resources Defence Council (NRDC) and the Environmental Defence Fund (EDF)*
Sector	*Energy*
Applicable RSA Step(s)	*Not applicable*
STO	*Strategic, Operational*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

The report was prepared for the Natural Resources Defence Council (NRDC) and the Environmental Defence Fund (EDF), and sets out a framework for assessing and selecting resilience regulatory policy options for America's electricity sector.

Methodology

The report emphasises that policy for America's electricity network need to look beyond supply reliability and consider the experience of the customer as the end user. It advocates expanding the system boundary of the energy system to include domestic premises (including localised storage or generation) and transmission, as well as further system elements all the way up to power generation and fuel supply. Lagging indicators of performance should be from a customer's perspective and should include frequency, scale and duration of electricity outages. An inclusive strategy should include how to ensure customers survive and rapidly recover from an extended outage. It recognises many solutions lie beyond the limits of the bulk power system and federal jurisdiction.

Analysis

The report offers a useful overview of how a holistic view, outside traditional system boundaries can offer benefits for an energy generation and distribution system. It does this by focusing on the actual experience of the end user and expands the scope of measures to improve resilience.

Suitability for RSA

Welsh Water's customer-focused approach already aligns well with the principles of this framework, and the organisation already considers measures to improve resilience that are beyond their traditional scope of control (such as domestic interventions). However, the framework is a useful reminder that the Resilience Systems Approach should consider the customer or end-user experience when analysing resilience.

Reference

Silverstein, A., Gramlich, R., Goggin, M., 2018, A Customer-focused Framework for Electric System Resilience, Grid Strategies LLC.

	High Value		Low Value
Grid operator, reliability coordinator	Interconnection rules Schedule coordination Fuel coordination Emergency planning and drills System & asset models Situational awareness		Generation capacity payments
T&D, Genco Capital	Distribution pole hardening Additional transmission paths and loops Back-up communications Transmission automation Distribution automation	T&D undergrounding Generator weatherization	 Coal & nuclear subsidies
T&D, Genco O&M	Tree trimming Cyber security & secure communications networks Physical security Mutual assistance Strategic spare equipment & mobile substations Situational awareness, system monitoring, PMUs Emergency planning and drills Outage management system		Fuel supply guarantees
Customer	Distributed generation, back-up generators Emergency supplies More efficient building shells Community critical infrastructure hardening	Insurance Distributed storage	

Figure 41: Relative value of measure to improve energy system resilience

XXI. Case Study: 100RC CoLab method

Developed by	*100 Resilient Cities*
Sector	*Cities*
Applicable RSA Step(s)	*2*
STO	*Strategic Operational*
Suitability	*Amber*
Ease of implementation	*Amber*

Overview

The 100RC 'CoLab' is a Collaboration Workshop designed by 100 Resilience Cities (100RC) to bring a wide range of stakeholders together and drive innovation and collaboration for solving problems that are too complex for any one sector or discipline to solve.

Methodology

The CoLab workshop is a 2-3 day workshop, generally based on qualitative processes and evaluation but may be supported by data or quantitative information, and typically guides the participants through the following five steps with the intention of developing 8-12 actionable solutions:

1. Set the scene: ensure all participants have a clear understanding of the topic and its relevance locally and globally.

This may be done through pre-reading, site visits, best practice case studies, local stakeholder presentations.

2. Use a Resilience Lens: define how the topic relates to the city's risk profile, resilience priorities and qualities of a resilient system.

May be done through group exercises and applying selected resilience frameworks to the CoLab topic.

3. Analyse the situation: identify the dynamics that are currently creating challenges, map the root causes and effects, identify work already underway and known best practices as well as gaps and needs for interventions.

May be done through group exercises around a problem tree; mapping out the issues at play in relation to the CoLab topic

4. Develop solutions: identify new services, tools, approaches, activities, and products that need to be applied/developed to address existing gaps.

May be done using design sprint methodology developed by Stanford University.

5. Plan next steps: agree and plan for next steps to advance the solutions.

Presentation to decision-makers, call for collaborators, work plan development, one-on-one meetings.

Analysis

By bringing together multiple stakeholders (either internal only or including potential investment partners or other external stakeholders), this facilitates a systems approach to resilience planning and investment. Mapping root causes and identifying overlaps can help identify more efficient investment solutions.

Suitability for RSA

Step 2. Development and prioritisation of mitigation options
The CoLab workshop format could be adapted to suit problem solving issues for development and prioritisation of mitigation options, and investment prioritisation for Welsh Water system resilience.
Whilst some of the specific aspects of the CoLab tool may not be relevant to the Welsh Water context, the broad structure and purpose of the workshop provides a good basis on which to develop a systems-based approach to resilience problem solving.

References

Silverstein et al., 2018, A Customer-focused Framework for Electric System Resilience

Figure 42: Initial outputs from the CoLab workshop run in Cape Town in 2018.

XXII. Case Study: 100RC Opportunity Assessment Tool (OAT)

Developed by	*100 Resilient Cities*
Sector	*Cities*
Applicable RSA Step(s)	*2*
STO	*Strategic*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

The Opportunity Assessment Tool (OAT) was developed by 100 Resilient Cities (100RC) to support cities in identifying and prioritising a wide variety of ongoing and possible initiatives that would help build resilience in a city. The format of the OAT is a spreadsheet, where initiatives are collated alongside the shocks and stresses they address, the resilience characteristics of the initiatives and their alignment with the resilience priorities for the city. The OAT helps the city to shortlist and prioritise the initiatives that will have the greatest impact on improving city resilience.

Methodology

The OAT tool gathers qualitative and quantitative information about potential initiatives in a 4-step process that filters initiatives based on the additional information gathered at each step. These steps go from high-level to detailed, allowing users to maximise efficiency by only entering the more detailed information for those initiatives that are taken forward at each stage. The four steps of the methodology are as follows:

1. Ideas bank:

The ideas bank is the first page of the spreadsheet in which basic information about each initiative is collected. The idea is that this is an evolving repository of initiatives that are identified through different processes. The ideas bank should capture all of these initiatives and ideas in one place for assessment in steps 2, 3 and 4.

2. Resilience filter:

The resilience filter helps the user(s) to begin filtering the initiatives for taking forward using multicriteria analysis based on whether the initiative has a clear connection to root causes or drivers of resilience and the shocks or stresses it responds to.

At the resilience filter stage, for initiatives that are less suited to the city's specific challenges, the user(s) may choose either not to take these initiatives forward, or to re-evaluate the design of the initiatives to better address the city's resilience priorities.

3. Resilience detail:

Step 3 focuses on those initiatives that have been taken forward from step 2, and therefore have some more detailed information associated with them. Further information is added in this stage, such as whether the initiative has other beneficial outcomes aside from the primary resilience aim, who the beneficiaries are and the level of support the initiative has from wider communities.

The work in step 3 results in calculating a score for each initiative, which is designed to provide an indicative and objective prioritisation based on the key criteria identified, before final shortlisting takes place in step 4.

4. Shortlist

The final shortlisting is carried out based on the scoring and information gathered during the previous stages. The user(s) can incorporate subjective or less tangible elements to the final shortlisting to manually incorporate initiatives, regardless of what the scoring from step 3 indicated.

In the shortlisting stage, requirements for next steps are also identified. The output of step 4 is a finalised shortlist of initiatives for the city to implement.

Following these steps, a set of automated analyses within the excel sheet summarise information about the shortlisted initiatives. This allows the user(s) to quickly assess the balance of shortlisted initiatives in terms of scale, status, type, links to resilience drivers and qualities of resilience and shocks and stresses they respond to. The user is encouraged at this stage to identifying the lead or owner of each initiative, potential funding sources and partners, challenges, required resources, next steps for implementation and anticipated outcomes.

Analysis

The OAT is a useful way to prioritise a long list of initiatives for building resilience within any system. The principles of a staged shortlisting process based on key criteria is a useful format for dealing with lots of information and many initiatives. Documenting clearly the key information about initiatives and their relevance to specific resilience challenges ensures an audit trail and allows for objectivity in assessment. The flexibility of the tool means that users can manually shortlist initiatives and are not held to the relatively crude scoring system.

Suitability for RSA

Step 2. Development and prioritisation of mitigation options
The OAT, or an adapted OAT with Welsh Water specific fields for information entry, could be useful for the development and prioritisation of mitigation options, in particular to support investment prioritisation. The exact criteria used for steps 2 and 3, and the basic information required in step 1, would probably need to be adjusted for incorporation into Welsh Water's RSA.

References

100 Resilient Cities, 2019, Opportunity Assessment Tool, https://www.100resilientcities.org/tools/opportunity-assessment/ Accessed on: 29/05/2019

XXIII. Case Study: Health Lead approaches to Infrastructure

Developed by	*Arup*
Sector	*Health*
Applicable RSA Step(s)	*2*
STO	*Strategic*
Suitability	*Green*
Ease of implementation	*Red*

Overview

The Health Asset Framework is an intentionally flexible health led approach to assessing a wide variety and capacity of infrastructure assets, taking into consideration the cross over between health and wellbeing and infrastructure.

Methodology

The report defines themes which align infrastructure, health and wellbeing.
It includes guidance to group health assets into six key dimensions (with further sub categories) and how to split these into physical and non-physical assets. These factors are: personal capacity, lifestyle and activities, community and economy, built environment, natural environment and climate and ecosystems.
This guidance includes the need to test categorisation with the asset groups specific stakeholders as they will vary depending on type of asset.

Analysis

The approach has been tested with a wide range of attendees including infrastructure, planning, public health, environmental economics, youth services, academia, arts and culture and community development groups.
Groups were asked to review the Health Asset Framework. The outcome was that the framework was found to broaden the conversation wider than that which would usually be associated with infrastructure assets. An additional outcome was that insights from the participants placed valuable focus on non-physical assets, highlighting that infrastructure projects could enable capacity building in these areas.

Suitability for RSA

The health led approach and the themes identifying convergence between infrastructure and health could be used as a lens through which to assess Welsh Water's infrastructure assets. The approach can be applied a varying scales and types of project.

References

Arup, Exploring a health-led approach to infrastructure, https://www.arup.com/perspectives/publications/research/section/exploring-a-health-led-approach-to-infrastructure Accessed on: 29/05/2019

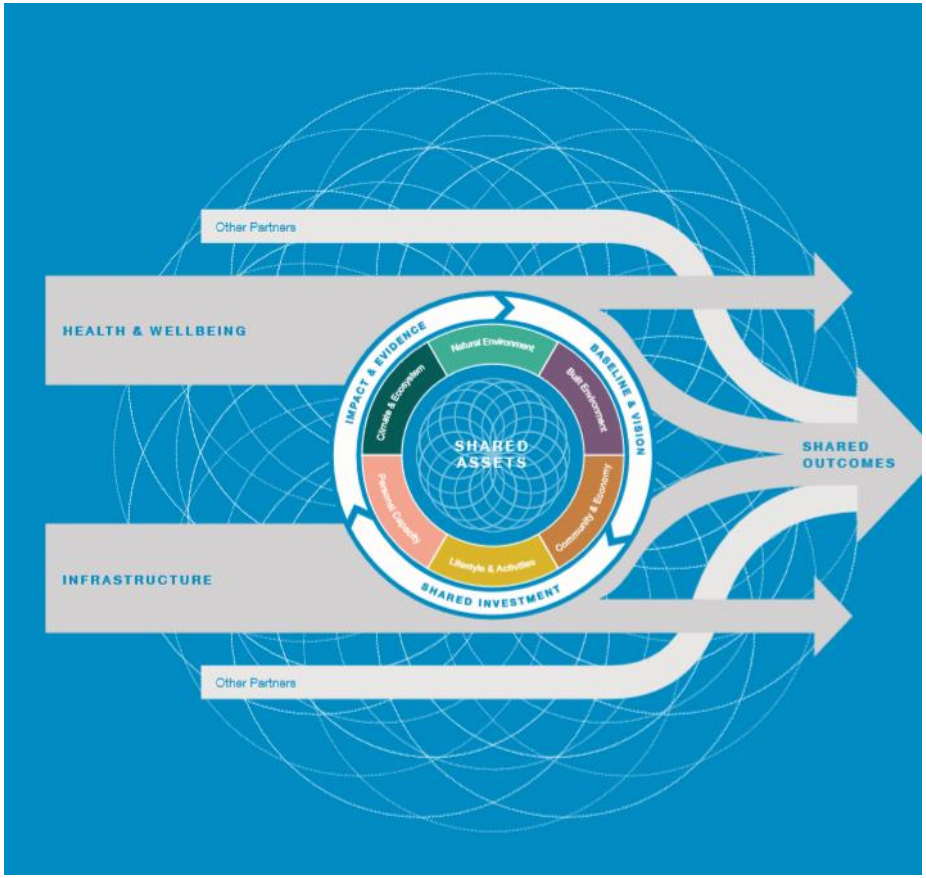


Figure 43: Health Asset Framework (Exploring a health-led approach to infrastructure, Discussion paper, Arup)

XXIV. Case Study: 4Ts and 4Rs

Developed by	*Cabinet Office and Department for International Development*
Sector	*Risk management*
Applicable RSA Step(s)	*2,3,4*
STO	*Strategic operational*
Suitability	*Green*
Ease of implementation	*Green*

Overview

The 4Rs and the 4Ts are qualities of resilience and methods of managing or treating risk, respectively.

4Rs	4Ts
Resistance	Transfer
Redundancy	Tolerate
Reliability	Treat
Response & Recovery	Terminate

Risk management responses can be one or a mixture of the 4Ts, and the mitigation measures can be one or a mixture of the 4Rs. The 4Ts and 4Rs provide value by helping determine good design, improve resilience and create an appropriate risk control strategy.

Methodology

As categories of approach, rather than a distinct process, there is no specific methodology to using the 4Rs and 4Ts but they can be applied within other stages of resilience assessment and resilience building work.

Analysis

The 4Ts have been mainly used in relation to risk management responses. They aim to support risk managers to provide extra value, by focusing risk management to ensure it is proportionate and provides suitable impact.

The 4Rs are qualities of a resilient approach, activity or component. These are different ways in which resilience provision can be delivered For an approach, activity or component to have a balanced approach to resilience it would ideally cover multiple of the 4R qualities of resilience. These qualities have been used in practice in various approaches in the water sector, for example Case study 15 United Utilities resilience review used them as a method to review asset investment.

Suitability for RSA

The 4Ts risk acceptance matrix can help to identify the type of mitigation solution that needs to be adopted.

Mitigation options may be assessed against the 4Rs in terms of their resilience characteristics or the resilience characteristics they are helping to build.

References

Cabinet Office (UK), 2011, Keeping the Country Running: Natural Hazards and Infrastructure

Le et al., 2018, Risk perceptions on cruise ships among young people: Concepts, approaches and directions

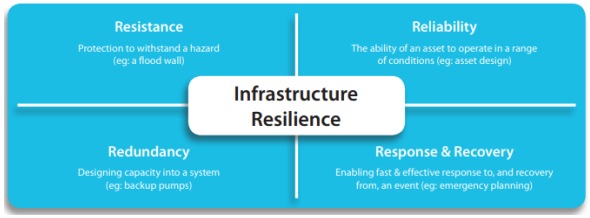


Figure 44: The 4Rs of resilience (as per Cabinet Office)

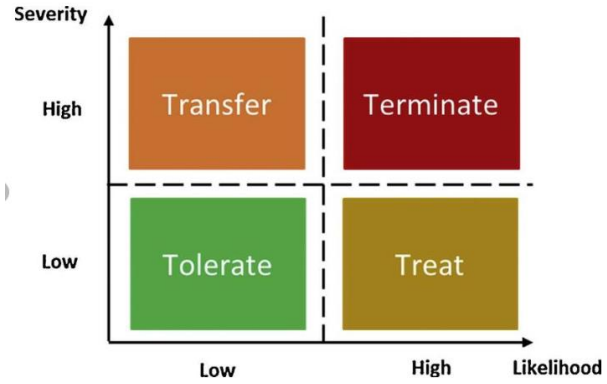


Figure 45: Risk Acceptance Matrix

XXV. Case Study: Resilience Shift – Defining and measuring value

Developed by	*The Resilience Shift*
Sector	*Cities*
Applicable RSA Step(s)	*3*
STO	*Operational*
Suitability	*Red*
Ease of implementation	*Amber*

Overview

The Resilience Shift programme produced a scoping study which emphasises that a "*resilient organisation has a clear vision that understands value, its dynamic nature and brings each part of the business together to sustainably and coherently create and protect that value within a disruptive and changing environment*."

Methodology

All infrastructure has a value chain through which services and supplies are delivered. The scoping study emphasises the importance of understanding the complete value chain, and where and how it is vulnerable. Knowing the relative importance of each link in the chain can help improve understanding of where the supply chain is susceptible to disruption or failure. An assessment around these principles can be an important process in helping to build resilience into a complex system. Designing a targeted set of assessment metrics can help to monitor and control value. The scoping study defines a value framework, identifying six different types of value which should be recognised (although it also notes these may be organisation-specific). The values presented in the framework are: 'utility', 'quality', 'time', 'social', 'environmental' and 'financial' value, which can all be quantified to some extent and the study identifies a series of potential metrics for assessing delivery of these values.

Analysis

The process is a high-level snapshot of the principle of a 'value chain', and how analysis of this chain can be a vital part of understanding organisational resilience. It is non-prescriptive but provides a useful thought process for those that are new to the concept of resilience.

Suitability for RSA

The approach is a useful way of framing individual risk quantification tools within the bigger picture of organisational resilience. Welsh Water should consider mapping its own full value chain, and integrating these principles into its overarching Resilient Systems Approach. The value framework in this approach could be useful to incorporate into the evaluation and prioritisation of mitigation options as well as when considering monitoring and review.

References

Look, R., Field C., 2017, Resilient Foundation Through Systems Thinking Summary Report, The Resilience Shift.

Figure 46: Infrastructure values framework

XXVI. Case Study: A capitals-based approach

Developed by	*Yorkshire Water*
Sector	*Water*
Applicable RSA Step(s)	*3*
STO	*Strategic, tactical or operational*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

Often a company's non-financial assets (both physical and non-physical) and a company's impact (both positive and negative) on external non-fixed assets are overlooked in decision making processes and not captured in reporting processes. A capitals-based approach focuses on identifying, measuring and reporting on non-financial impacts and dependencies to support improved decision making.

Methodology

The International Integrated Reporting Council (IIRC) aimed to encourage sustainable development though considering six capitals in company valuation. This capitals-based approach has been adopted by Yorkshire Water and embedded into their Decision Making Framework (DMF). Yorkshire Water's six capitals approach includes the following capitals:

- **Financial capital**- financial health and efficiency
- **Manufactured capital**- pipes, treatment works, offices and IT
- **Natural Capital**- materials and services relied upon from the environment
- **Human Capital**- working forces capabilities and wellbeing
- **Intellectual Capital**- knowledge and processes
- **Social Capital**- relationships and customers trust.

The DMF includes a six capitals impact assessment tool which quantifies risk and value to optimise investment decisions about assets and operations.

Analysis

The six capitals approach provides the opportunity to express non-financial impacts and dependencies in monetary terms, allowing them to be directly compared. This provides the opportunity to understand the benefits.

Suitability for RSA

This approach could be an effective method to ensure the Welsh Water considers the full range of essential functions and identifies suitable criteria when developing its investment prioritisation process.

References

The International Integrated Reporting Council IIRC. Capitals: Background paper for <IR> [Internet]. International Integrated Reporting Council;
2013. Available from: https://integratedreporting.org/wp-content/uploads/2013/03/IR-Background-Paper-Capitals.pdf
Yorkshire Water, 2018, The six capitals in our Decision Making Framework. Online
https://www.yorkshirewater.com/sites/default/files/Yorkshire_Water_DMF_website_case_study.pdf

Capital		Example Valuations
Natural		Crops and livestock Global climate Air quality recreation
Social		Physical activity Quality of place Trust
Human		Employment Health & Safety Local economy
Intellectual		Skills Intellectual property
Financial and Manufactured		Delivery costs Private costs of failure Private benefits / income

Figure 47: Yorkshire Water's 6 Capitals and example valuations

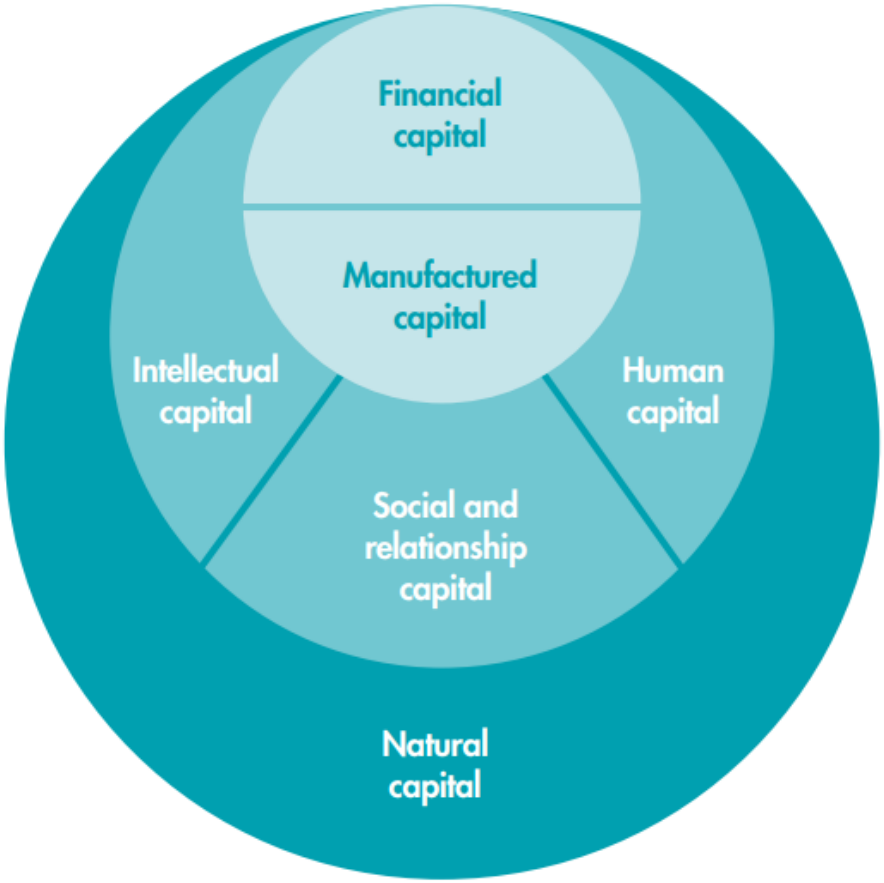


Figure 48: IIRC 6 Capitals diagram

XXVII. Case Study: Resilience Value Realisation

Developed by	*100 Resilient Cities*
Sector	*Cities*
Applicable RSA Step(s)	*3*
STO	*Strategic operational*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

Resilience Value Realisation (RVR) helps implementing stakeholders come to a shared understanding of resilience value of a specific initiative and develop a roadmap of the steps necessary to protect it. The methodology was developed by ValueLab through funding from The Rockefeller Foundation.

Methodology

The RVR approach involves being very specific about the need for resilience, the beneficiaries, and how a given opportunity can create resilience and to address any challenges impacting the delivery of resilience value as an integral part of project development. It is carried out through a workshop and is organised around five stages, starting with understanding the current status, developing a need statement, customer value proposition and an opportunity statement to reflect where participants would like to be on the issue in question in the future. This leads to the development of a roadmap for realising that opportunity with potential blockers identified.

Analysis

The RVR helps to not only identify those activities that will truly bring resilience benefits, but also helps anticipate challenges that may arise so that the participants can think about the way that the roadmap is delivered to minimise or mitigate these issues.

Suitability for RSA

Incorporating a RVR evaluation step into all Welsh Water operations and investment decisions would help embed resilience thinking into business as usual decision making.
The aim of the process is to extend resilience thinking beyond dedicated processes that already exist, and into the day-to-day operations and long-term planning of the business.

References

100 Resilient Cities, 2019, Resilience Value Realization, http://www.100resilientcities.org/tools/resilience-value-realization/ Accessed on: 29/05/2019

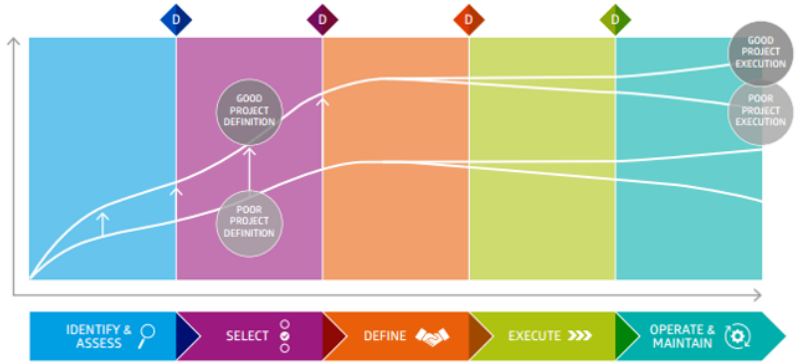


Figure 49: RVR Process

XXVIII. Case Study: Dynamic Adaptive Policy Pathways

Developed by	*Academia*
Sector	*Policy Research*
Applicable RSA Step(s)	*2*
STO	*Tactical*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

This is method used for planning under uncertain conditions. This uses both adaption pathways, which is a way of presenting alternative routes to get to the same desired point in the future, and adaptive policymaking. It's a theoretical approach to planning that involves describing different types of response and monitoring to see if adaptation is required.

The Dynamic Adaptive Policy Pathways (DAPP) approach has been set out in a number of academic studies and used by Deltares in relation to flood risk management for the RISES EU research project BASE ('Bottom-up climate adaptation strategies towards a sustainable Europe'). A similar process has also been undertaken by Affinity Water for their WRMP. It has been used in practice for large infrastructure projects and at national scales.

Methodology

Adaptation pathways is an analytical approach for exploring and sequencing a set of possible actions based on alternative external developments over time. Adaptive policy making is a theoretical approach considering a planning process with different types of actions. Both methods are brought together in dynamic adaptive policy pathways. The adaptation pathways method refers to 'adaption tipping points' as conditions under which an action no longer meets the specified objective. After reaching such a tipping point, additional actions are needed in order to reach the intended goal and the pathway element provides a sequence of possible actions.

The tipping points are created from scenario development, and whilst the nature of this approach is inexact, the overall range of possibilities does need to be reasonable in terms of likelihood. The pathways are manually drawn, based on model results or expert judgement. All have to meet a pre-specified minimum e.g. safety norms. Where the performance of an action becomes unacceptable, the pathway is becomes a dotted line. Actions with long 'sell-by-dates' are at the top and those with shorter time periods closer to the current plan. Illogical action pathways are eliminated (shown as greyed out in Figure 50) Where preferred pathways diverge, this indicates a decision point which could be the start of a discussion on an adaptive plan. The short-term action is one that meets all conditions/perspectives. Actions can be further assessed for impact, tipping point and costs.

Analysis

Adaption pathways provide decision makers with the tools to identify opportunities, no-regret actions, and the timing of actions in a

changing environment. This therefore aids planning in the long and short term. It shows an insight into sequencing of actions over time, considering transient scenarios, meaning that a variety of uncertainties can be planned for. Rather than analysing what happens if a certain scenario materializes it explores under what conditions a certain policy/action starts to fair. This still requires a computational scenario approaches to be carried out e.g. Monte Carlo Analysis.

Suitability for RSA

This adaption tipping points may be a useful tool to consider for an optioneering process. There are examples of DAPP methods being used in workshops via gamification, which could be transferable to Welsh Water's RSA. DAPP has been highlighted as a potential tool to be used in the updated WRMP approach.

References

Haasnoot et al., 2013, Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world, Global Environmental Change

Lawrence et al., 2017, What it took to catalyse uptake of dynamic adaptive pathways planning to address climate change uncertainty, Environmental Science & Policy

Buurman er t al., 2017, Adaptation Pathways and Real Options Analysis: An approach to deep uncertainty in climate change adaptation policies, Policy and Society

Baker et al., 2015, WRMP 2019 Methods – Decision Making Process: Guidance

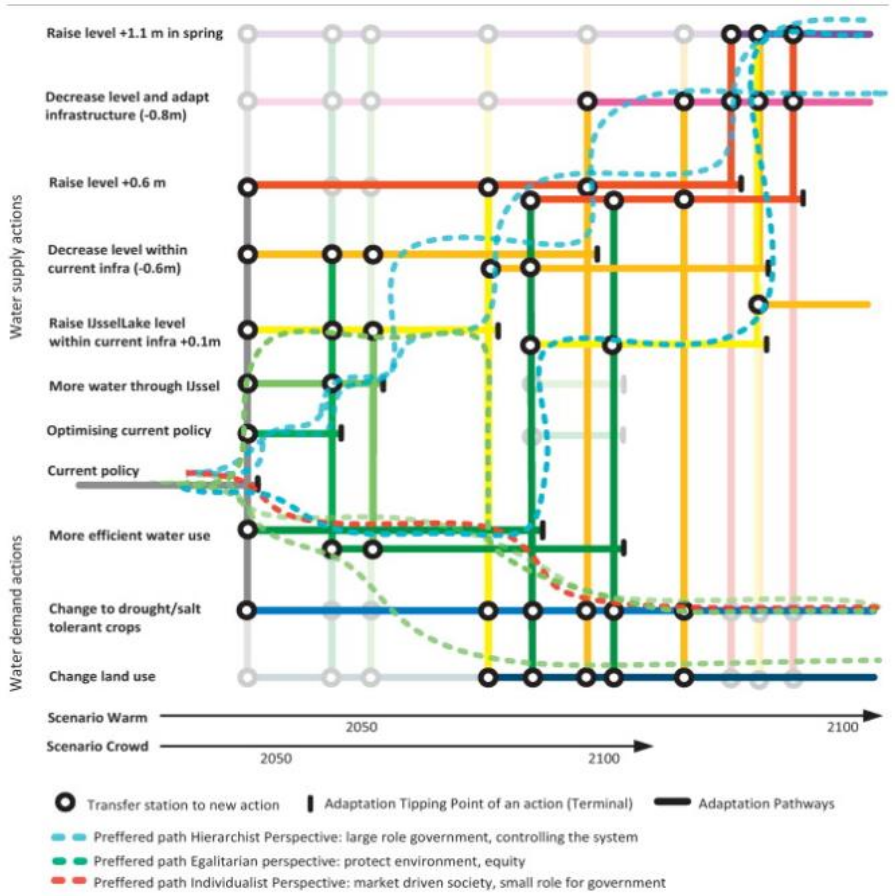


Figure 50: Adaptive pathways dotted lines shows the use of preferred pathways

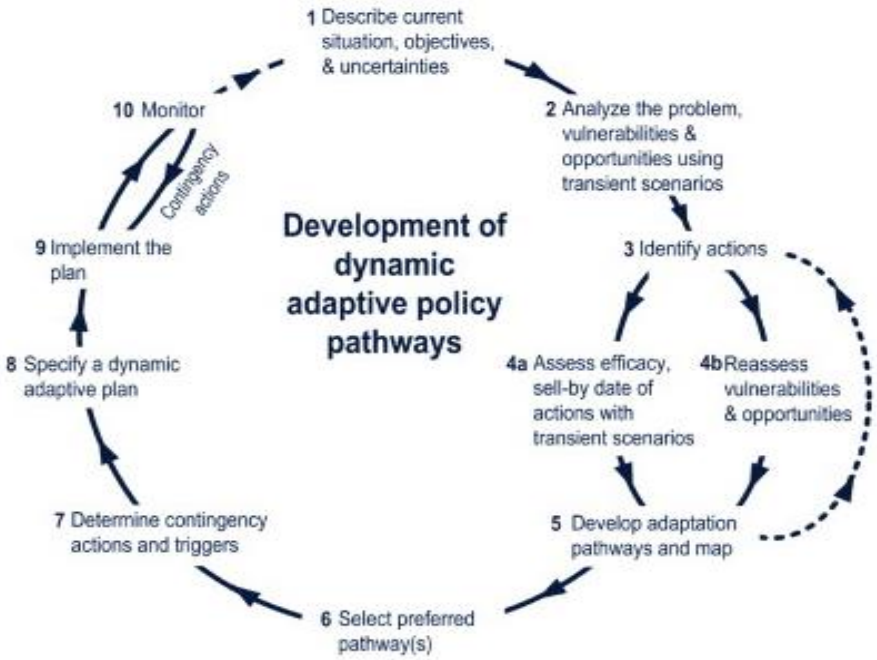


Figure 51: The Full dynamic adaptive policy pathway approach which combines adaptation pathways and adaptive policy making

XXIX. Case Study : WFGA ways of working and indicators

Developed by	*Welsh Government*
Sector	*National guidance*
Applicable RSA Step(s)	*4*
STO	*Operational*
Suitability	*Green*
Ease of implementation	*Amber*

Overview

The Well-Being of Future Generations (Wales) Act 2015 (WFGA) provides the framework for sustainable development in Wales.

Under this legislation, public bodies listed in the Act have a duty to carry out sustainable development, defined as "*the process of improving the economic, social, environmental and cultural well-being of Wales by taking action, in accordance with the sustainable development principle, aimed at achieving the well-being goals*."

The Act defines seven national well-being goals and outlines five ways of working that will help public bodies deliver the well-being goals. A set of 46 indicators sits beneath the goals to help measure progress over time.

Methodology

The Future Generations Framework for projects was published in draft by the Office of the Future Generations Commissioner for Wales. It was created "to support the public sector and others in Wales to deliver projects and infrastructure fit for the future". The Framework provides a series of prompts to consider through project development and delivery, which can be used to align the project with the local well-being objectives set by public bodies, well-being goals and embed the ways of working.

Analysis

The WFGA has been referred to as a flagship piece of legislation that enshrines the rights and consideration of future generations into decisions made today. The indicators are broad and not all will be directly relevant to Welsh Water's activities, but the principles underlying the work and the example of setting holistic indicators is relevant to Welsh Water's Resilient Systems Approach.

Suitability for RSA

The indicators for the WFGA have already been used to map the relationship between the UN SDGs and the WFGA wellbeing goals. Welsh Water could consider adopting some of the indicators as metrics for assessing how their operations and plans are meeting the wellbeing goals under the WFGA 2015.

References

Future Generations Commissioner for Wales, 2019, Well-being of Future Generations (Wales) Act 2015,

http://futuregenerations.wales/about-us/future-generations-act/ Accessed on: 29/05/2019

Welsh Government, 2016, National Indicators for Wales

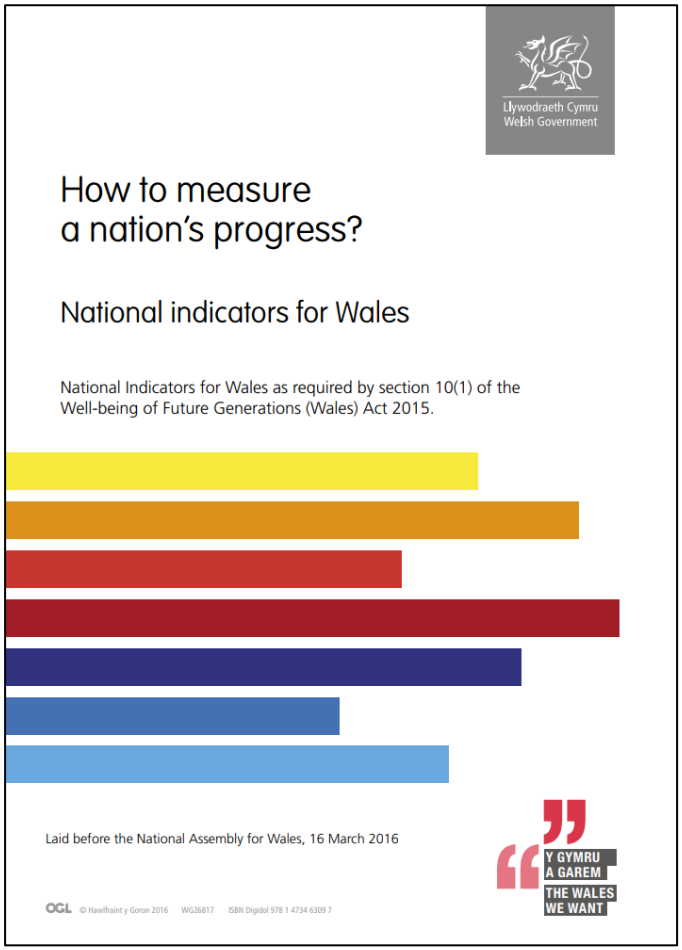


Figure 52: National Indicators for Wales