A framework for the operationalisation of resilience in the water sector

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I certify that all material in this thesis which is not my own work has been identified and that any material that has previously been submitted and approved for the award of a degree by this or any other University has been acknowledged.

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Abstract

Global threats such as a changing climate, rapid population growth, and increasing levels of urbanisation, will continue to pose major challenges to the water sector over the coming years. Within the UK, questions over future water supply, delivery, and demand all form a central part to this argument, with the themes of resilience and sustainability often employed in the response. Recent national events, along with changes to legislation and policy, have resulted in the need for the concept of resilience to develop from a theoretical concept into a tangible operational method. Despite a rise in popularity and use of the term resilience, within both the water sector and wider society, there remains a lack of clear consensus on what resilience really is for the sector, and how it can be applied with actions implemented at the operational level. A combination of methodological approaches, data collection and analytical methods have been used to develop a strategic framework for the operationalisation of resilience theory in the UK water sector.

A pilot study questionnaire, and semi-structured interviews with members of the Northumbrian Water workforce have provided insight into core issues surrounding resilience understanding and the historic application of the term within the water sector. Semi-structured interviews with water sector executives have contributed to an example of how an existing resilience framework can be used to develop a methodology for resilience analysis. A case study example using the outbreak of the COVID-19 pandemic has provided insight into the sectors ability to plan for and respond to acute external events. The use of focus groups conducted with members of the operational workforce to co-develop a resilience based mobile application have contributed to the development of an application to aid the operationalisation of resilience. The thesis has also led to the development of a strategic framework to aid the operationalisation of the resilience concept within Northumbrian Water and the wider water sector.

Key conclusions from this research highlight a continued focus on the physical engineered assets in comparison to the social, a lack of clear understanding of the

term and wider concept of resilience, and a failure to prioritise long term planning and preparation across both Northumbrian Water and the wider UK water sector. The development of a research methodology using the Safe & SuRe framework has provided an example of how existing frameworks can be used for additional analysis. The co-development of a resilience based app has provided an example of a mode for increasing resilience understanding and communication within the organisation, and identification of resilience based interventions. Required changes that were identified before the concept of resilience can be further operationalised within NW include the need and desire for internal resilience focussed educational programmes, rewarding of long term planning, and the need to make the introduction of new ways of working personal to the user.

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List of Abbreviations

CCW	Consumer Council for Water
CEMPS	College of Engineering, Mathematics and Physical Sciences
CIWEM	Chartered Institution of Water and Environmental Management
CLES	College of Life and Environmental Sciences
GDPR	General Data Protection Regulation
HRO	High Reliability Organisations
IPCC	Intergovernmental Panel on Climate Change
NAT	National Accidents Theory
NW	Northumbrian Water
OED	Oxford English Dictionary
Ofwat	Water Services Regulation Authority
PR	Price Review
RE	Resilience Engineering
REM	Ripple Effect Map
RWA	Regional Water Authorities
SDG	Sustainable Development Goals
SES	Socio-ecological Systems
UK	United Kingdom
UKRI	United Kingdom Research and Innovation
UN	United Nations
VBA	Visual Basics Application
WASC	Water and Sewerage Company
WHO	World Health Organisation

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Publications

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Lawson, E., Bunney, S., Cotterill, S., Farmani, R., Melville-Shreeve, P., Butler, D., (2021), COVID-19 and the UK water sector: Exploring organizational response through a resilience framework, *Water and Environment Journal,* 00:1-11, doi:10.1111/wej.12737.

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Chapter 1: Introduction

This thesis aims to develop a strategic framework for the operationalisation of resilience theory in the UK water sector. The thesis does this by undertaking detailed assessments of the current understanding and status of resilience in the UK water sector, and developing a resilience based application for use at the operational level in water and sewage companies (WASC). An example of how a resilience based theoretical framework can be used as an assessment tool is also provided, alongside analysis on the UK water sector's response to the COVID-19 pandemic. In addition, the thesis provides policy and practice recommendations to enhance the sector wide operationalisation of resilience based measures.

The motivation for this research stems from the understanding and realisation that the UK water sector is facing a multitude of ever increasing global threats, in which the term resilience is often used as a response. However, there remains a lack of a clear consensus on what resilience really is for the sector, and how it can be applied with actions implemented at an operational level. This includes application of existing resilience based theoretical frameworks.

This chapter provides an introduction to the research by first presenting the research background from a national and international perspective (Section1.1). This is then followed by the context for the research (Section 1.2) and rationale (Section 1.3), an outline of the research plan (Section 1.4) which includes aim, objectives, research questions and methods, the originality and contribution of knowledge (Section 1.5), and an outline of the structure of the thesis (Section 1.6).

1.1 Background

As the world around us continues to change, the need for sustainable and resilient systems is greater than ever before. A changing climate, increasing urbanisation and continually evolving global demographics have resulted in ever increasing levels of

uncertainty. An increase in extreme events, categorised as low probability, high consequence events in terms of magnitude, spatial scale and severity of consequences, continue to further contribute to such global levels of uncertainty.

Within the arena of global sustainability and resilience, the water sector often emerges as a priority area for immediate action. Specifically, as the complex relationship between water, a changing climate and the effects changes in societal behaviour have on water supply, are truly a global issue. In 2001, the Intergovernmental Panel on Climate Change (IPCC) stated in their first Assessment Report the connection between vulnerabilities faced by the global water sector and the need for increased adaptation and adaptive capacity (Arnell *et al*., 2001). Since then, further IPCC reports, the World Health Organisation (WHO) and the United Nations (UN,) have all highlighted the need for increased sustainability and resilience of water supply and sanitation systems. More recently, the UN highlighted the sustainable management of water and sanitation as one of the seventeen Sustainable Development Goals 2015-2030 (SDGs). SDG 6 targets issues surrounding water efficiency, sustainability of supply and integrated water resource management at all levels. The recent COP26 conference which took place in Glasgow, 2021 again highlighted the need for further protection and better management of the world's water resources. Although there was an increase in countries understanding the significance of water for effective climate control prior to COP26, it was noted that many water- related solutions continue to not be used to their full potential (Herbart-Coleman, 2021).

For the UK, a changing climate and increasing temperatures are expected to significantly alter rainfall trends, therefore impacting water quality and availability, as well as the health of the aquatic environment (Prudhomme *et al.*, 2012). With general trend predictions being one of warmer wetter winters, drier summers, and an increase in extreme weather events (Lowe *et al.*, 2019; Water UK, 2016). Such changes to precipitation patterns and the projected scale of the threats have highlighted the need for further action as part of the strive for sustainable and resilient water management systems.

The UK population is expected to reach 76 million by 2045, compared with 65 million in 2015 (Office for National Statistics, 2017). The projected rise in population, coupled with increases in summer temperatures and decreases in rainfall has resulted in predictions of repeatedly increased long and short duration droughts (Defra, 2016). The perceived threats to the water industry are not only centred around physical climate-related threats such as supply of natural resources and the reliability of engineered infrastructure, but also include social pressures seen across wider society. These include changing demographics and labour markets, concerns over cyber security (Ofwat, 2017a), and changes to demand patterns regarding quantity and geographic distribution, as highlighted by the COVID-19 pandemic (Cotterill *et al*., 2020). The rapidly evolving nature of such threats and pressures enters new levels of complexity when combined with the reducing customer tolerance of failure to meet required levels of performance (Ofwat, 2017a).

In addition, the profile of environmental hazards in the UK has repeatedly been pulled to the forefront of public consciousness as extreme climate-related threats and their associated impacts become more frequent. The changes and evolution on how and where threats are presenting themselves (seasonality, geographical location, magnitude and duration) has resulted in a perceived society wide acknowledgement for the need to ‘do more’. With the majority of large-scale events that have occurred in the UK over recent years involving either floods or droughts, conversations around the water sector and its more specific roles and responsibilities have again risen to the forefront of national discussion.

In the UK, the privatisation of the ten Regional Water Authorities (RWA) of England and Wales in 1989 brought with it a new regulatory regime that was centred on promoting economic efficiency, whilst simultaneously improving drinking water and environmental quality. Over three decades later, despite multiple changes in regulatory and operating environment the core focus of the industry remains the same- cost efficiency, water and effluent quality, and environmental protection. However, increasing internal and external pressures and threats have resulted in a scenario in which water companies and service providers must continue to not only

find ways to operate and maintain performance, but also provision of service in such variable and extreme conditions.

As a response to the ever-changing threat profile of the water sector and scenario in which the industry is required to operate, the term resilience has been increasingly cited as a response to the issues. In 2014, changes to the Water Act *(Water Act (England and Wales) 2014 c.2*., 2014) provided the Water Services Regulation Authority (Ofwat), the sectors economic regulator, with a primary duty to further its resilience objective within the water sector. The amendment to the Water Act 2014 now requires water companies to:

> (a) Secure the long-term resilience of water undertakers' supply systems and sewage undertakers' sewage systems as regards environmental pressures, population growth and changes in consumer behaviour, and
>
> (b) To ensure that undertakers take steps for the purpose of enabling them to meet, in the long term, the need for the supply of water and the provision of sewerage services to customers *(Water Act (England and Wales) 2014 c.2*., 2014).

Such changes have resulted in the sector now being legally required to implement resilience based actions across its operations. However, the exact meaning of resilience, and how it is interpreted and then applied or operationalised within the context of the water sector has yet to be agreed upon.

Although multiple strategies and theoretical frameworks have been developed and defined at a strategic level (Butler *et al.*, 2016), it is understood that many decision-makers consider the content to be too abstract, and far from daily activity (Iturriza *et al.*, 2019). The need to provide decision makers with guidance on operationalising resilience, and how to move from theoretical concepts to building resilience through tangible measures, highlights the repeated need to make resilience concepts both useful and useable beyond their theoretical context (Iturriza *et al.*, 2019). The need for resilience has been successfully highlighted across all levels of society, however

if it is to move on from a point of academic deliberation and a society wide buzzword, guidance on, and tools for targeted practical application must be provided to decision-makers and sharp-end operators.

Use of the term operationalisation has also increased over recent years, both within sustainability and resilience focused academic literature and wider society (Osmundsen *et al.*, 2020; Parsons and Thoms, 2018; Wardekker *et al.*, 2010), as the need to make more abstract concepts tangible becomes ever more necessary. For this thesis the term operationalisation is understood as 'turning abstract concepts into measurable observations and implementable actions'.

This thesis places focus on the operationalisation of the concept of resilience and how a resilience based theoretical framework can be applied at both the strategic and tactical level, contributing to tangible outcomes across the organisation. The Safe & SuRe water management project (Butler *et al*., 2016) provides further context for this project and is elaborated on in the following section.

1.2 Research perspective

This chapter provides an overview of the context of the situation in which the research was undertaken.

1.2.1 Context – Safe & SuRe intervention framework

This research adopts the Safe & SuRe approach to urban water management (Butler *et al*, 2014), and applies the Safe & SuRe theoretical framework (Butler *et al.*, 2016) and associated definitions throughout. The Safe & SuRe approach proposes an intervention framework as a response to the growing threats and uncertainties now faced by urban water systems. This approach applies the understanding that systems must first have a level of reliability before resilience and then finally sustainability can be attained (Figure 1.1).

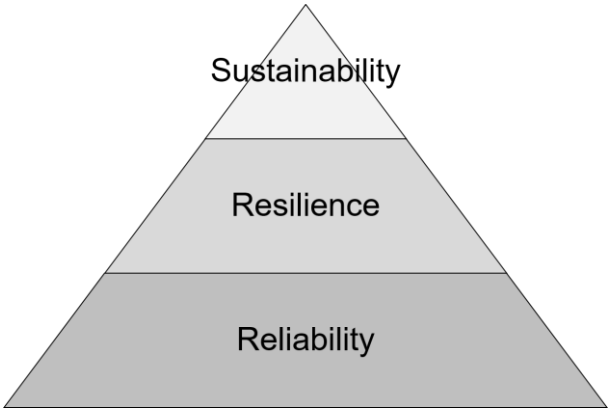


Figure 1.1 Sustainability, Resilience and Reliability (Source: Butler *et al*., 2014)

The Safe & SuRe framework provides a diagrammatic representation of the relationship between threats and their consequences and enables opportunities to identify interventions aimed at increasing system resilience and therefore sustainability. This approach is based on the premise that urban water management systems have traditionally been designed to provide reliable (Safe) level of performance, however as unknown threats and a changing climate continue to disrupt the steady state, a transition to a system that is centred on sustainability (Su) and resilience (Re) is now required (Butler *et al.*, 2014, 2016).

The Safe & SuRe approach defines resilience as the *"degree to which the system minimises level of service failure magnitude and duration over its design life when subject to exceptional conditions*" (Butler *et al.*, 2016, p. 65). With regards to this thesis, it is important to note that the term 'system' refers to and encompasses the social, economic, environmental, political and engineered aspects of the system in question.

The Safe & SuRe Intervention Framework consists of four elements, threat, system, impact and consequences. Threats are defined as *"any event with the potential to reduce the degree to which the system delivers a defined level of service"* (Butler *et al.*, 2016, p. 66). Thus, threats have the potential to cause failure within the system with the resulting impacts having negative consequences for society, economic performance and or the environment. Throughout the wider resilience, emergency

and disaster management literature the terms threat and hazard can be defined individually or used interchangeably. As the Safe & SuRe framework does not distinguish between the two, within this research the term hazard will be considered as per the definition identified for threat.

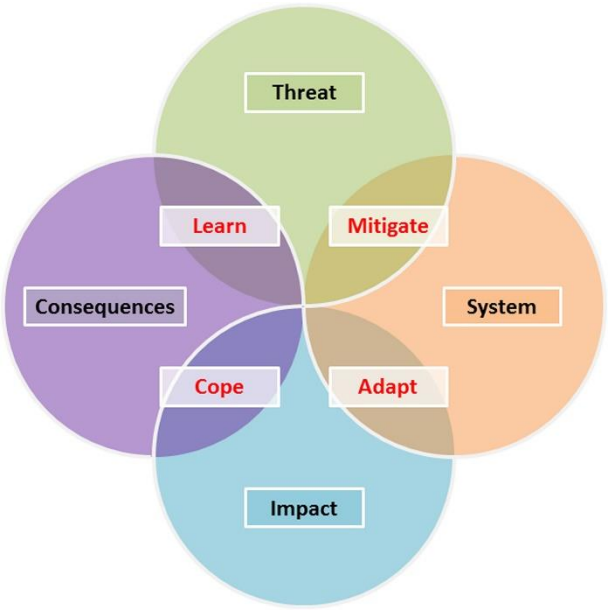


Figure 1.2 Safe & SuRe Framework (Source: Butler *et al*., 2016)

The areas of intersection between each of the four elements as shown in Figure 1.2 show points for the intervention measures of mitigation, adaptation, coping and learning. Together the intervention measures aim to minimise the frequency, magnitude and duration of the consequences of threats that urban water management systems are facing.

The framework can be applied using a top down, bottom up, middle based or circular approach to analysis (Figure 1.3). The top-down approach facilitates analysis that is representative of the traditional risk management approach to emergency planning and system management. This is based on the identification and anticipation of known threats or hazards and the implementation of mitigation measures to ensure maintenance of required level of system performance. However, issues with this approach are centred around the need for all threats to be known with the ability to predict the associated impacts and consequences.

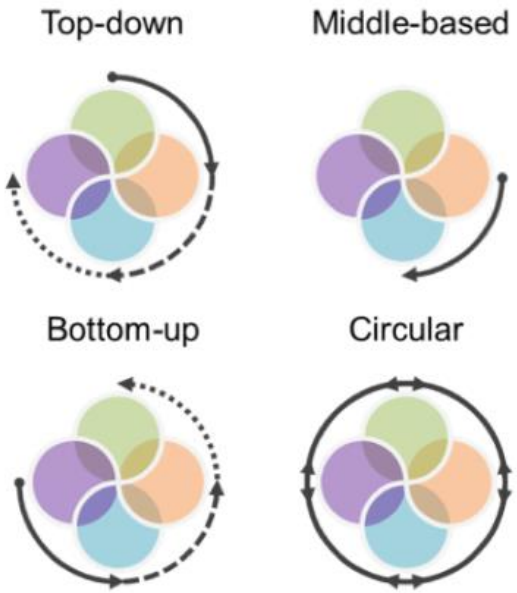


Figure 1.3 Directional analysis using Safe & SuRe Framework (Source: Butler *et al*., 2016)

The bottom-up approach suggested by Safe & SuRe therefore provides an alternative to the top down approach, which instead focuses on consequence based analysis. Here analysis is consequence based and coping focussed, as it starts with the identification of potential social, economic or environmental consequences and works in an anti-clockwise direction around the framework. An advantage of this approach is considered to be that consequence analysis can be carried out without detailed assessment of threats or impacts, instead focussing on how an individual entity (person, organisation, community) would be able to cope without a critical, service or system (Butler *et al*., 2016).

In comparison to top down and bottom up, the Safe & SuRe approach is primarily focused on middle based analysis and recognises that it is impossible to identify every possible threat to the system. This approach instead focuses on failure modes of the system and how they impact overall system performance, whilst acknowledging that different threats may result in the same modes of system failure with the ability to be addressed through one form of adaptation. Finally, circular analysis, as identified by the Safe & SuRe approach, considers threats, system failure modes, impacts and consequences as part of a circular arrangement (Figure

1.3) with a focus on learning. The circular approach enables capacity for preparedness and ability to respond to be built at multiple differing levels across the system in question, resulting in improved resilience and sustainability (Butler *et al.*, 2016).

Why Safe & SuRe?

Although many resilience frameworks exist in both academia and industry, the Safe & SuRe framework (Butler *et al.*, 2014, 2016) was chosen for this project as a theoretical resilience framework that had been specifically developed with, and for, the water sector. The collaborative and consultative approach taken at the start of the Safe & SuRe project with a range of practitioners and policy makers, to ensure that the needs of the stakeholders were met, resulted in an existing buy-in from the industry. It was considered that the existing awareness of the Safe & SuRe approach and framework, both within the project sponsor, and across the industry would aid the development of this research project.

1.2.2 Research context

This EngD was undertaken as part of the UKRI Engineering & Physical Sciences Research Council Industrial Doctorate Centre STREAM [EP/L015412/1] and was completed at the Centre for Water Systems, University of Exeter. The project started in October 2017 with the researcher spending the first three months (Oct-Dec 2017) based at Cranfield University, completing the compulsory taught aspect of the STREAM EngD programme. The researcher then moved to be based at the University of Exeter in Jan 2018 to begin the research project itself. In July 2018, the researcher moved to be based within the project sponsor where they were based until March 2020. The outbreak of the COVID-19 pandemic prevented the researcher from returning to be based at the University of Exeter for the final part of the project as was originally planned. The project was sponsored by Northumbrian Water, with the researcher based in industry for 80% of the time. Such industrial sponsorship has created a focus on the water sector, and associated policy of England and Wales. The majority of data collection was conducted remotely within Northumbrian

Water following a change in methodology due to the COVID-19 pandemic, and the resulting restrictions.

In June 2020, the researcher was presented with the opportunity to join a multi-disciplinary group of researchers looking at the effects of the COVID-19 pandemic, and organisational challenges facing the UK water sector. The COVID-19 centred work was facilitated by the Chartered Institution of Water and Environmental Management (CIWEM) who provided access to their member base and professional contacts for the data collection processes. The COVID-19 work was split into three phases, with a different member of the research team leading each of the phases. Phase two of the project, which the author of this thesis was lead researcher for, focussed on organisational and operational response by the UK water sector to the COVID-19 pandemic. It is the results from phase two of this work that are presented in Chapter 5 of this thesis.

1.3 Rationale

Following changes to policy and legislation ('Water Act (England and Wales) 2014 c.28', 2014), water and wastewater service providers in England and Wales are now required to secure the long term resilience of systems. However, how resilience can be effectively operationalised and moved beyond a traditional engineering and single cause and effect model of risk management remains to be seen.

Although changes to policy initially occurred in 2014 the bulk of resilience based measures, within the UK water sector, still exist at the strategy level and are yet to filter down to the operational level. Reasoning behind this is often attributed to the fact that decision makers consider the content to be too abstract and far from the daily activities of operational workers (Iturriza *et al.*, 2019).

This project therefore aims to develop a strategic framework for the operationalisation of resilience theory in the UK water sector. The aim will be achieved by undertaking a detailed assessment of the current understanding and

status of resilience in the UK water sector, and developing a resilience based application for use at the operational level. The application developed will help users to identify potential intervention measures aimed at reducing the impact and consequences of threats, whilst also contributing to the creation of a culture of resilience at the operational level. This research also provides examples of how resilience frameworks and more specifically the Safe & SuRe resilience framework, can be used as an assessment tool at the strategic level to produce tangible outcomes.

1.4 The research plan

This research has been undertaken using a consultative approach of engagement and enabling knowledge co-production between the researcher and water sector employees. This section presents an outline and justification of the research aim, objectives and methods for data collection.

1.4.1 Aim, objectives and research questions

As established in the preceding sections, adequate methods or strategies for the operationalisation of resilience at the operations level in the water industry have yet to be introduced. In order to facilitate a transition to this, the aim of this thesis is:

"To develop a strategic framework for the operationalisation of resilience theory in the UK water sector".

In order to achieve the aim the following objectives have been determined:

Objective 1: To explore the current status of 'resilience' in the UK water sector.

Objective 2: To understand the concept of resilience within the context of the UK water sector.

Objective 3: Investigate how an existing resilience framework can be used to assess organisational resilience within the UK water.

Objective 4: To develop a resilience based application for use in the UK water sector.

Objective 5: To develop policy and practice recommendations to enhance the successful operationalisation of resilience within the UK water sector.

These objectives are summarised in Figure 1.4, which also outlines the research questions, the research methods used, and the chapters in which they are further investigated in. Considering the broad nature of the above objectives a number of research questions were determined to better facilitate the selection and application of research methods. The research questions for each objective are outlined below.

Objective 1: To explore the current status of 'resilience' in the UK water sector.

i. What are the reasons for promoting the notion of resilience in the UK water sector?
ii. How is resilience currently understood in the UK water sector?

Objective 2: To understand the concept of resilience within the context of the UK water sector.

i. How is resilience currently applied to the UK water sector?
ii. What are the existing barriers to operationalising resilience in the UK water sector?

Objective 3: Investigate how a theoretical resilience framework can be used to assess organisational resilience within the UK water sector.

i. How can the Safe & SuRe framework be used to design a research methodology?
ii. How can the Safe & SuRe framework be used to assess system performance?
iii. How did the UK water sector respond to the COVID-19 pandemic?

iv. How has the COVID-19 pandemic impacted the resilience of the UK water sector?

Objective 4: To develop a resilience based application for use in the UK water sector.

i. What should the central aims of the application be?
ii. What platform should an online resilience application be developed on?
iii. Which level of the workforce should the application be tailored too and why?
iv. How should the results/data be displayed?
v. How can the application contribute towards the development of a resilience culture?

Objective 5: To develop policy and practice recommendations to enhance the successful operationalisation of resilience within the water sector.

i. What are the current organisational themes that need to be considered in the dissemination of a resilience strategy?
ii. How would a resilience based online application fit with current operational practices?

1.4.2 Research methods

This research has employed both quantitative and qualitative methods for data collection and analysis. Quantitative data collection was facilitated by means of a questionnaire survey tool administered amongst the workforce of a UK based water company. Qualitative data collection methods used include semi-structured interviews with wider water sector executives, and semi –structured interviews and focus groups with operations based members of the project sponsors workforce. The quantitative data were analysed using both descriptive and inferential methods. Qualitative data analysis focussed on thematic analysis of interviews and focus groups. These are presented in further detail in Chapter 3.

1.5 Originality and contribution to knowledge

This research has developed a strategic framework for the operationalisation of resilience theory in the UK water sector. The research provides a detailed overview of the current status of resilience within the UK water sector, and how resilience is currently viewed by members of the workforce. Semi-structured interviews and a questionnaire survey with members of the NW workforce provide insight into how the term is understood, and how methods of operationalisation are currently implemented. The research demonstrates a desire within the workforce to be provided with more information on the concept of resilience and what it means with regards to their individual roles. This research moves away from the historical engineering centred approach to resilience, as results highlight specific areas in which both individual organisations and sector policy makers can take immediate action to improve the operationalisation of resilience in the UK water sector, by making changes to the social aspect of socio-technical systems.

The Safe & SuRe framework has traditionally been used to explore the resilience of physical systems (Butler *et al*., 2016). This research provides an example of how the Safe & SuRe framework can be used to develop a qualitative based research methodology and to assess the resilience of socio-technical systems. The research shows how the Safe & SuRe framework can be applied at the sector level within the context of an acute external threat, and further demonstrates the diversity of the framework and the many opportunities for use.

The development and co-creation of a new mobile app based on the Safe & SuRe framework provides new insights into how a method of co-creation can be used with operational staff to develop a tool for use at the operational level. The development of the app, based on the Safe & SuRe framework, has provided a further example of how an existing resilience framework can be used at the tactical level by WASC operators. Further semi-structured interviews have provided insight into how the resilience app can then be disseminated across operational teams.

1.6 Thesis plan

The thesis plan presented in Figure 1.4 demonstrates how a structured and methodological approach was taken to explore how resilience can be operationalised within the UK water sector, using the objectives outlined in Section 1.4. and how the thesis will proceed.

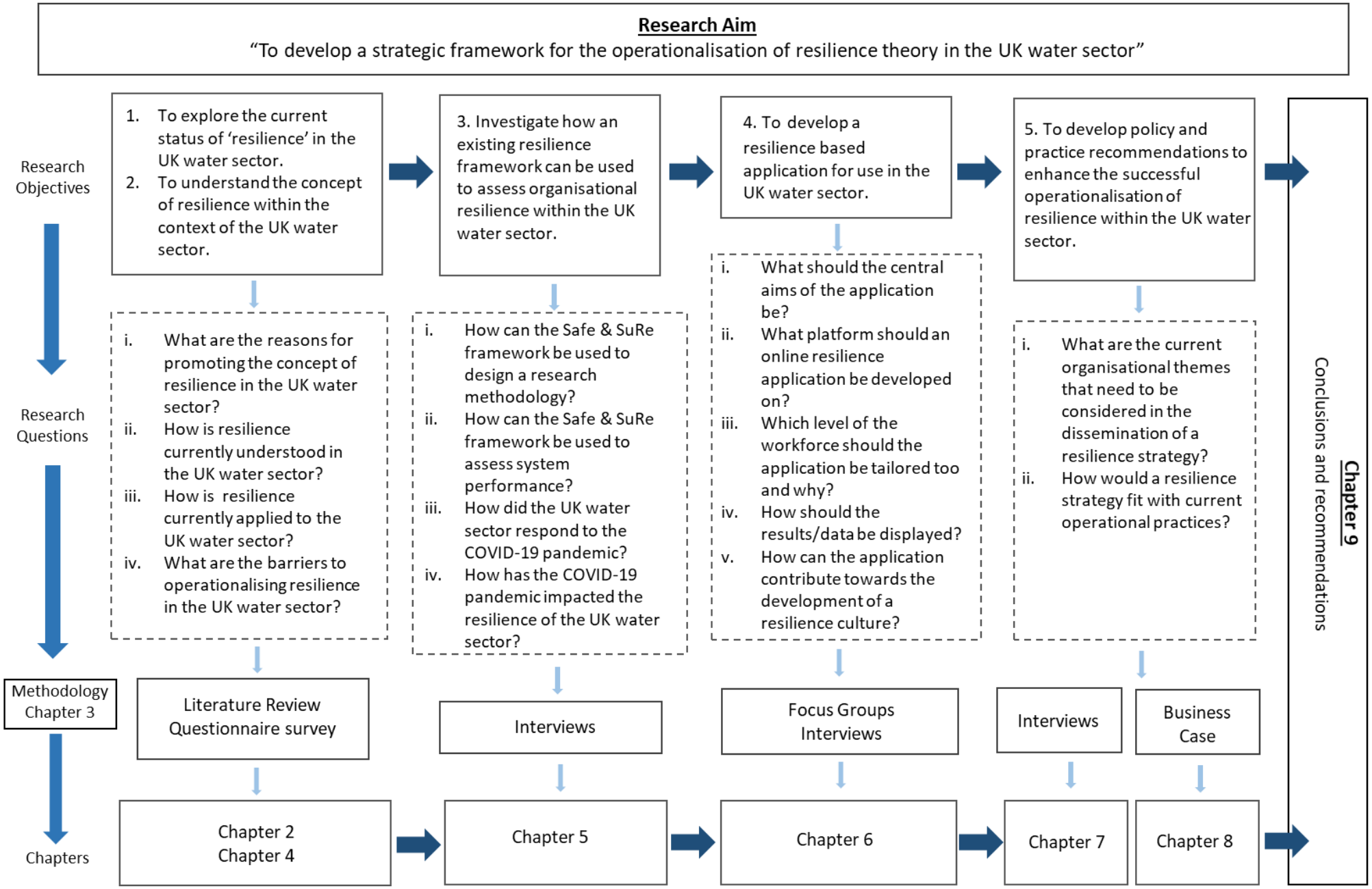


Figure 1.4 Thesis Plan

Chapter 2: Literature Review

Parts of this chapter are published as:

Lawson, E., Farmani, R., Woodley, E., and Butler, D., (2020), A Resilient and Sustainable Water Sector: Barriers to the Operationalisation of Resilience, Sustainability, 12,1797.

This chapter provides a review of the literature that contextualises the research. The sub-topic areas were identified by taking a holistic view of the resilience of the UK water sector and the wider resilience literature, as well as providing background to the water sector in England and Wales. This chapter aims to address the objectives and associated research questions outlined below.

Objective 1: To explore the current status of resilience in the U.K. water sector.

Objective 2: To understand the concept of resilience within the context of the UK water sector.

The broader context of the UK water sector is first discussed, before the concept of resilience, its wider definition and definition with relation to the water sector, and associated resilience principles are outlined. Discussion then moves on to cover systems thinking in Section 2.5, organisational resilience in 2.7 and finally the operationalisation of resilience in Section 2.8. Finally, a summary of the chapter findings is provided in Section 2.9.

2.1 Water governance in the UK

With regards to England and Wales, water governance and supply has undergone a significant change over the past 60 years (Figure 2.1). Prior to the 1960s, water supply and sewerage services were mostly managed on a city or town basis through regional municipalities, which had in themselves developed on an ad-hoc basis. The

sporadic and non-regulated mode of development resulted in more than 1000 bodies involved in the supply of water and 1400 responsible for sewage and sewage disposal, with provision of services remaining separate from planning (Ofwat, 2006). During the 1960s, water planning was moved to a national level due to the establishment of a statutory water resources board which was subsequently abolished during the 1970s–1980s (Ofwat, 2006). Following this, 10 new regional water authorities were established under the Water Act 1973, which were responsible for managing water resources and supplying water and sewerage services on a fully integrated basis (Figure 2.1). The area that each of the new water authorities covered was broadly based on river catchment areas (Ofwat, 2020). It was this catchment-based structure that was then taken forward for the start of the privatisation process in 1989. It is however important to note that the water sectors in Scotland and Northern Ireland did not undergo the process of privatisation and therefore their governance structures remain separate and publicly owned.

Privatisation of the water sector in England and Wales in 1989 not only created new opportunities for operating and investing, but also a new tightly monitored regulatory environment in which the new publicly listed companies must now operate. The newly created Environment Agency replaced the National Rivers Association and took control of the health of the aquatic environment, with the Drinking Water Inspectorate (DWI) created to reassure customers on the quality of drinking water supply. The 1991 Water Industry Act brought with it the Water Services Regulation Authority (Ofwat) for economic regulation and the Consumer Council for Water (CCW) to help manage customer relations (Pearce *et al.*, 2013). An outline of regulatory bodies and their key responsibilities is provided in Table 2.1.

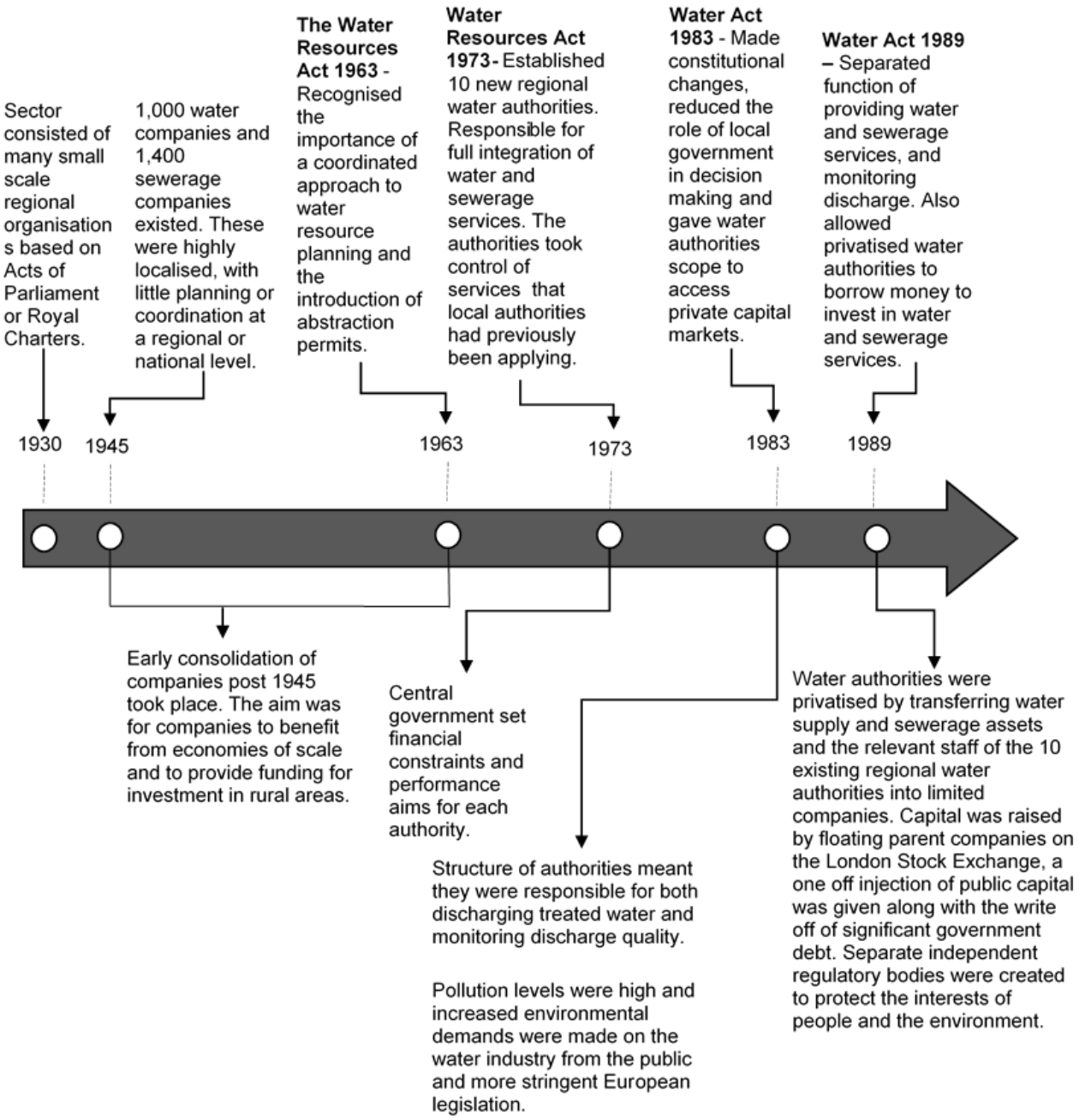


Figure 2.1 Water sector overview pre-privatisation

Table 2.1 Water Sector Regulators England and Wales.

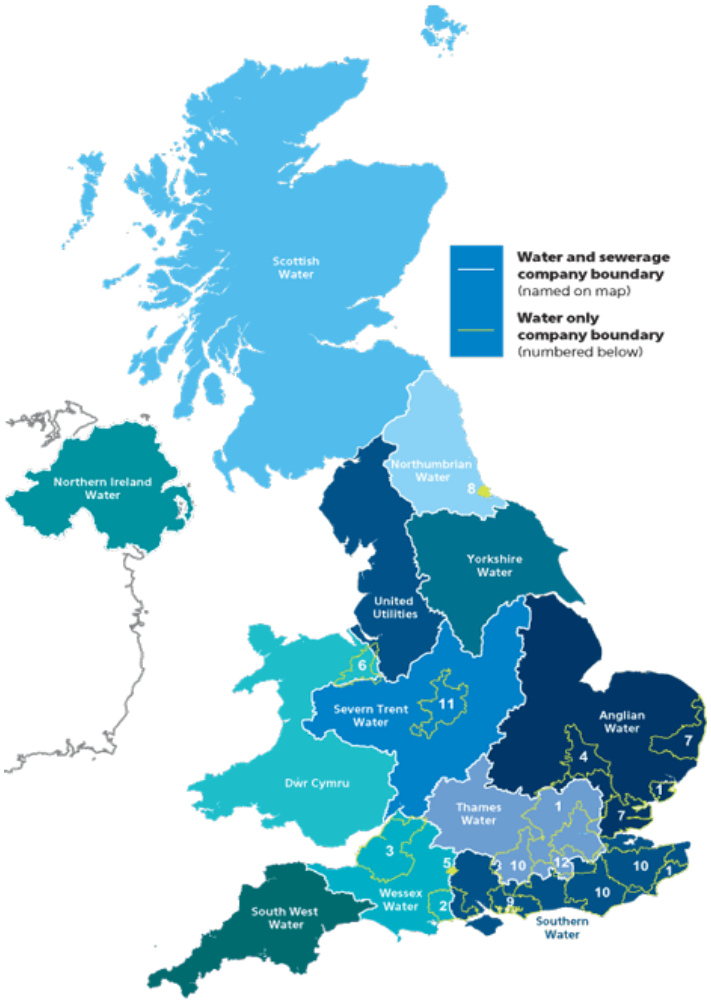
Regulator	Industry Name	Description	Key Responsibilities
The Water Services Regulation Authority	OFWAT	A non-ministerial government department that is the economic regulator for the water and sewerage sectors in England and Wales. They are responsible for making sure that companies they regulate provide consumers with a good quality and efficient service at a fair price.	– Protect the interests of customers – Ensure companies carry out statutory functions – Where appropriate promote competition – Promote economy and efficiency
Environment Agency	EA	An Executive non-departmental public body responsible to the Defra Secretary of State. They decide how much water can be abstracted from the environment and sets and enforces standards for the return of treated wastewater to the environment	– Ensure environmental quality and pollution standards are met. – Provides licences for abstraction and discharge – Manage and enforce company work relating to flood and drought management
Drinking Water Inspectorate	DWI	Responsible for enforcing drinking water quality standards in England and Wales.	– Enforce drinking water quality standards
Consumer Council for Water	CCW	Represents customers interests relating to price, service and value for money. Investigates customer complaints about water quality.	– Represent customers – Investigate customer complaints
Department for Environment Food and Agriculture	DEFRA	The UK government department responsible for water policy and regulations in England and Wales. Sets drinking water quality and environment standards which water companies must adhere to.	– Sets overall water and sewage policy framework in England – Works closely with Welsh Government who are responsible for overall water and sewerage policy framework in Wales. – Create special permits (e.g., drought orders) when required

At the time of privatisation, the government stated the much-needed injection of capital, and high levels of debt as the key driving force. Infrastructure was of poor quality with high levels of environmental pollution occurring. Since 1989, investment in infrastructure and services has resulted in long term improvements. The regulatory structure that was developed to regulate the new privatised companies has helped steer the sector in the right direction, with the use of regulatory price controls from Ofwat generally balancing the interests of customers with shareholders. However, debate does still exist around the role of large-scale multinational corporations in the provision and ownership of such a necessary commodity, especially in regard to the scale of shareholder dividends alongside volatile company performance on measures relating to leakage and pollution. At present the water sector in England and Wales consists of eleven companies that provide water and wastewater services, and nine that provide water only (Figure 2.2), with five sector regulatory bodies. Scotland and Northern Ireland both have one water and wastewater provider.

Along with changes to the legality of water governance it is also important to note the relevance of changes to paradigms of water management (Bell, 2020; Plummer and Baird, 2021), and more specifically the hydro-social contract between water users and providers. Under privatisation, water is defined as both a natural resource and a commodity (Pearce *et al.*, 2013), hence changing the provider-user relationship, with the water user becoming a customer who pays for use of a commodified resource. Here, users have access and 'rights' to an abundant water supply of a defined quality, with very few responsibilities other than paying the bill on time. As all knowledge of water supply, infrastructure function and maintenance, along with details of consumption patterns remain the responsibility of water service providers (Sofoulis and Strengers, 2011).

The continually changing relationships between water user and provider, along with the concept of responsibility are important to note when discussing the topics of resilience and sustainability. Questions over the concept of responsibility with regards to water supply in the UK were again raised during the initial outbreak of the

COVID-19 pandemic, as domestic water consumption increased by 20-40% across the UK (Cotterill *et al.*, 2020; Lawson *et al.*, 2021).



1. Affinity Water
2. Bournemouth Water
3. Bristol Water (South West Water)
4. Cambridge Water
5. Cholderton and District Water
6. Dee Valley Water
7. Essex & Suffolk Water (Northumbrian Water)
8. Hartlepool Water (Anglian Water)
9. Portsmouth Water
10. South East Water
11. South Staffs Water
12. Sutton and East Surrey Water

Figure 2.2 Water and Sewerage companies of the UK (Adapted from Terry, 2018)

2.2 What is resilience, and why now?

In recent years, the term ‘resilience’ has seen a sudden and marked increase in use, in both academic, and policy discourse. Hosseini *et al.,* (2016) state that ‘resilience’ originates from the Latin word ‘resiliere’, meaning to bounce back. With the common use of the term typically implying the ability of an entity or system to return to a

‘normal state’ following the occurrence of an event which has disrupted the steady state (Hosseini *et al.*, 2016).

Such an explosion in prevalence of the term (Meerow *et al.*, 2016) has resulted in the word resilience evolving into a multidisciplinary and multifaceted term (Bhamra, Dani and Burnard, 2011; Juan-García *et al.*, 2017). One with multiple applications and a range of meanings that are often dependent on the situation or scenario in which it is applied. Use of the term ranges from a metaphor linked to sustainability and the governance of risk, to a property of a dynamic model, to a measurable quantity that can be assessed and applied in the field (Carpenter *et al.*, 2011; Welsh, 2014). At present, there is no widely agreed upon definition that is suited to or relevant for all applications and uses of the term. Discussions on whether there ever should be, or even can be one singular, interdisciplinary definition continue to appear throughout the literature (Southwick *et al*., 2014).

Defining resilience and understanding whether it is, or is being used as, a feature, a philosophy, or a capability (Bhamra *et al.*, 2011) has been the topic and indeed aim of many academic, government and industry based studies (Butler *et al*., 2014; Butler *et al*., 2016; Cabinet Office, 2011; Smith, 2012; Welsh, 2014). With the sheer volume of work out there on the definition of the word enough to base an entire research project on. Many resilience based studies are often centred around whether resilience is present or absent. However Southwick *et al.,* (2014) argue that taking such a binary approach and view can be misleading, as in reality, resilience is more likely to exist on a continuum that may be present to differing degrees across multiple domains of life (Pietrzak and Southwick, 2011 cited by Southwick *et al.*, 2014). Klein, Smit and Goosen, (1998) argue that in order to enhance resilience it is necessary to have a good initial understanding of what it is and its determinants, along with how it can be measured, maintained and improved.

The concept of resilience and therefore the use of the term has a rooted background in fields ranging from psychology and disaster management to engineering and ecology with increasing application in business, economics, and technology (Vale,

2014). Although multiple definitions and meanings are outlined and proposed in the differing fields, it is suggested that many actually *"deploy resilience in a similar way by viewing it as a way to conceptualise response to disturbance"* (Vale, 2014, p. 192). Independent of this view, the use of multiple contradictory definitions, often within the same field of study, or industry sector, have all equated to the term 'resilience' becoming little more than a buzz word with a lack of collective understanding (Linkov *et al.*, 2014; Lundberg and Johansson, 2015), and with the potential to *"collapse into the meaninglessness that results from having too many meanings"* (Vale, 2014, p. 192).

Linkov *et al*., (2014) and Smith and Fischbacher, (2009) suggest that although the ever present debate around meaning and definition continue to be of interest to the academic community, it can have serious implications for both the design and implementation of resilient systems, and the need for a transition into an operational paradigm for system management. Walker *et al*., (2004) simply state that the many different interpretations of the word 'resilience' cause confusion.

Early resilience based literature mainly consisted of, and focussed on, conceptual work aimed at developing a static knowledge base through the establishment of fundamental concepts and principles (Bhamra *et al*., 2011; C.S. Holling, 1973; Holling, 1996). This in turn resulted in the concept of resilience receiving little systematic and empirical work dedicated to proving or putting into action any theories suggested. However, more recently, studies based around the development of frameworks to aid implementation and application of resilience based activities, systems, and practices across a wide range of fields and sectors are becoming much more numerous (Butler *et al.*, 2016; Gonzales and Ajami, 2017; Helfgott, 2018; Linkov *et al.*, 2013; Milman and Short, 2008; Nikolopoulos *et al.*, 2019). Yet, as earlier stated a lack of common understanding within sectors, departments and fields of work, continue to hinder the ability to fully harness resilience within all domains.

Over the past decade there has been a growing acceptance that increasing uncertainty and variability in the hydro-climatic cycle, along with increasing pressures related to urbanisation, will create issues for water planners across the globe (Rodina, 2019). This has in turn resulted in global policy discourse embracing the concept of resilience as a necessary addition to water governance aimed at addressing climate change based impacts and additional external stressors. Within the UK, such embracing of the concept of resilience can be seen through the changes made to the Water Act 2014 and the inclusion of a primary duty for Ofwat to further its resilience objective within the sector ('Water Act (England and Wales) 2014 c.28', 2014). Such changes to legislation and the creation of a legal requirement for water companies to:

> *"Secure the long-term resilience of water undertakers' supply systems and sewage undertakers' sewage systems as regards environmental pressures, population growth and changes in consumer behaviour"*

firmly cements the concept of resilience within the context of the UK water sector. The inclusion of 'securing long-term resilience' as one of the four main themes in the 2019 Price Review (PR19) (Ofwat, 2017b), continued to further the resilience agenda for the water sector of England and Wales.

2.3 Defining resilience

A large majority of the literature references the study of resilience as evolving from the disciplines of psychology and psychiatry in the 1940s, with much of the accreditation given to Norman Garmezy, Emmy Werner and Ruth Smith (Waller, 2001, Johnson and Wielchelt, 2004, cited by Manyena, 2006). Here the study of resilience developed as a result of efforts to understand the aetiology and development of psychopathology in studies of children considered at risk of psychopathological disorders due to parental illness, inter-parental conflict and or poverty (Manyena, 2006). Such early studies were focussed on the analysis of risk and the negative adverse effects of traumatic stressors on children, which ultimately

saw the emergence of terms such as ‘resilience’, ‘stress-resistance’ and ‘invulnerability’ (Manyena, 2006). With the notion and concept of resilience later emerging as the one that took hold, gradually evolving into the widely disputed term we have today.

Initial use of the term ‘resilience’ within the physical sciences was to denote the characteristics of a spring and to describe the stability of materials and their resistance to external shocks (Davoudi *et al*., 2012a). In the 1960s, in conjunction with the rise of systems thinking, the use of ‘resilience’ within the field of ecology began to increase, where a seminal paper by Crawford Stanley Holling, a Canadian theoretical ecologist, published in 1973 made a clear distinction between engineering and ecological resilience (Davoudi *et al.*, 2012a). These two such approaches, one centred in ecology, the other in engineering, are what have continued on to form the basis of resilience understanding with regards to physical systems (Walk*er et al*., 2002; Gunderson, 2018), and specifically in the context of this research project, how resilience is understood with regards to water systems.

2.3.1 Ecology

In the 1970s, ecological theory in general was dominated by the notion that ecosystems have one fixed point of equilibrium or point of stability (Smith, 2012). Therefore ecologists tend to focus on the long term viability and nature of ecosystems, referring to resilience as a measure of a system’s ability to return to its original balance following a disruption, such as a sudden reduction in population due to an individual event (Vale, 2014).

It is within the field of ecology that resilience as a term, was first widely popularised by Holling, (1973), in the piece of work titled ‘Resilience and Stability of Ecological Systems’. This has since formed the foundation and working definition for most pieces of work focusing on both specific ecological resilience (Bhamra *et al.*, 2011) and broader areas of study looking to incorporate the general notion of resilience. Holling’s (1973) work differs slightly from general ecological theory, so far as it

instead proposes that ecosystems have multiple domains of stability which can be moved between (Smith, 2012). Holling's (1973) work outlines how viewing the behaviour of ecological systems from different viewpoints will result in the need for alternative approaches to management of said systems. The study outlines that resilience determines the persistence of the relationships within systems and is therefore a measure of the ability of these systems to absorb changes of state variables and parameters, and still persist. Here resilience is not only defined as how long it takes for the system to bounce back after a shock, but also how much disturbance the system can handle whilst remaining within critical thresholds (Davoudi *et al*., 2012a). Holling's study suggests that there are two main viewpoints regarding ecological systems, one of resilience and one of stability. Resilience emphasises domains of attraction and the need for persistence with the notion of extinction being not the result of a random event, but instead from the interaction of random events, deterministic forces and activities. Stability however emphasises the concept of a state of equilibrium and the maintenance of predictability with little fluctuation. Stability is here defined as the ability of a system to return to a state of equilibrium after a disturbance (Holling, 1973). The differing viewpoints of resilience and stability itself sparked interest with each sprouting their own line of theoretical enquiry (Folke, 2006; Smith and Fischbacher, 2009; Walker *et al.*, 2002).

2.3.2 Engineering

In comparison to this, engineering tends to view resilience as more of a mechanical process of bouncing back from a perturbation or event with a focus on the reliability of a system and the period of time it takes the system to return to a state of normal functioning. Hollnagel, Woods and Leveson, (2006) cited by Hosseini, Barker, & Ramirez-Marquez, (2016, p. 48), present engineering resilience as *"the intrinsic ability of a system to adjust its functionality in the presence of a disturbance and unpredicted change"*. Recognising and understanding the workings and normal functioning of a system as well as how it fails is considered an important aspect of engineering resilience (Hollnagel, 2011a; Hosseini et al., 2016).

The engineering resilience definition concentrates on the stability near to an equilibrium or steady state, and uses resistance to disturbance and speed of return to the point of equilibrium to measure the property or level of resilience (Holling, 1996). Where in comparison ecological resilience emphasises conditions far from a steady state equilibrium, where disturbances or events have the potential to flip a system into another behaviour regime, or to another domain (Holling, 1973). In this case the measurement of resilience is based on the magnitude of disturbance that can be absorbed by the system, by changing variables and processes that influence behaviour, without losing its fundamental characteristics (Walker *et al*., 1969 cited by Holling, 1996).

Holling, (1996) argues that the two differing aspects of a systems stability, one that focuses on maintaining efficiency of function (engineering), and one that focuses on existence of function (ecological), have very different consequences for evaluating, managing and understanding the complexity and change within, and of, a system. Although both discuss the need for the existence and maintenance of function, neither refer to required system performance which often differs from baseline function.

Holling, (1996) continues to argue that the two differing viewpoints are so fundamental that they *"become alternative paradigms whose devotees reflect traditions of a discipline or of an attitude more than of a reality of nature"* (Holling, 1996, p.33). That those who use, refer to, or side with the engineering definition predominantly draw from traditions of deductive mathematical theory (Pimm, 1984 cited by Holling, 1996), where those who side with the ecological resilience definition come from traditions of applied mathematics and applied resource ecology aimed at the scale of ecosystems. It is the evaluating, managing and understanding the complexity and change that occurs within a system, which is crucial to both understanding the term resilience, as well as its appropriate and effective application and use.

2.3.3 Disaster Management

The field of disaster management offers a further approach to defining resilience through one concerned with both ecological and social resilience, as well as socio-ecological spaces in between. Here the focus on socio-ecological systems signals a view that incorporates aspects of both the need for existence of function as well as efficacy of function, as the wider situational context and contributing factors are highlighted as critical in understanding how hazards and vulnerabilities shape resilience outcomes (Weichselgartner and Kelman, 2015).

As outlined by Kuhlicke, (2013), despite the diverse and polymorphic discussion around the definition of resilience, there is one common theme present within most arguments in the disaster management literature. Here resilience is often defined as a systems *capacity* to adapt or respond to a singular event (Kuhlicke, 2013). Therefore the overall orientation of the discourse, is how the notion of resilience can be used to enhance, build, or develop organisations, communities and systems ability to come to terms with new and unexpected events (Kuhlicke, 2013).

Research carried out by Manyena, Machingura and O'Keefe, (2019) within the field of disaster management, analysed 83 resilience definitions and outlined five phases of resilience covering the period of time from 1970 to 2016.

- Phase 1: 1970s - resilience as persistence and absorption
- Phase 2: 1980s - resilience as bounce back and return to equilibrium
- Phase 3: 1990s - resilience as prevention, anticipation and adaptation
- Phase 4: 2000s - resilience as transition, flexibility, bounce-forward and transformability
- Phase 5: 2010s - resilience as a neoliberal construct

This analysis traced the evolution of the concept of resilience, again highlighting the diversity of meanings and conceptual confusion of the term. The influence of engineering, ecology and the discourse surrounding the 'bounce-back' ability can also be traced through the evolution of the term. The development of the five phases of resilience runs along-side the earlier more general shift in thinking on disasters. Fuerdi, (2007) as cited by (Manyena *et al.*, 2011) traces what are perhaps the three

main shifts in disaster 'thought' which are *Acts of God; Acts of Nature;* and *Acts of Men and Women*.

From the beginning of time, disasters were explained as mere *Acts of God* implying that there was little to be done with regards to prevention and management. Later during the 'Age of Enlightenment', the emergence of science resulted in the causation of disasters shifting to *Acts of Nature*. Here, disasters were blamed on hazards, and hazards were disasters *per se* (Manyena *et al.*, 2011). It was not until the 1970s that disaster causation shifted from *Acts of Nature,* to *Acts of Men and Women*, when O'Keefe *et al.,* (1976) argued that disasters were instead a consequence of vulnerability, and therefore removed the naturalness from natural disasters. Such acknowledgement of change and evolution in defining and interpreting the term and associated concepts is important for how we then perceive and apply the concept of resilience. Such understanding is again imperative to the outcome or purpose of resilience, especially in regard to the question 'resilience to what ends?'.

Within the field of disaster management, the emergence of resilience as a concept brought with it a shift in focus to self-reliance as a counter to vulnerability, with Twigg, (2007) cited by Manyena, (2011) arguing that the terms 'resilience' and 'vulnerability' are opposite sides of the same coin. However Manyena, (2006) argues instead that vulnerability and resilience lie on the same continuum but on opposite ends, with vulnerability being negative, and resilience positive. Manyena *et al*., (2011) suggests that it would therefore be appropriate to assume that when referencing vulnerability, that resilience would also be referenced as dual terms, meaning the absence of one indicates the presence of the other.

2.3.4 Defining resilience for the water sector

In comparison to solely engineered or ecological systems previously discussed, water and wastewater systems are considered to be greater than a sum of their engineered parts, and can be described as socio-technical, or socio-ecological

systems which involve multiple complex interactions between human, technological and environmental components (Smith, 2012b). This however brings with it further complexity with regards to defining the term resilience, especially if resilience is to become more than a buzzword and a true operational concept.

As the role and importance of complex system dynamics in a human-dominated planet are becoming increasingly acknowledged, the focus of environmental resource governance is shifting from an approach that manages for efficiency and cost focussed optimisation to one that fosters the ability of systems to be flexible, reorganise and adapt (Rodina, 2019). With water systems considered to be among those most critically affected by global environmental change, global water policy discourses are now embracing resilience as a necessary and transformative approach to deal with the impacts of climate change and other external and internal threats (Rodina, 2019). However, defining resilience with regards to water systems within the academic literature is less explicit.

In a study of water sector based resilience literature conducted by Rodina, (2019), it was found that of the selected study group *"many papers do not provide explicit definitions of resilience and tend to use the term in a broad or vague way"* (Rodina, 2019, p. 6). The study found that of those that do define resilience, the differences in how resilience is conceptualised in relation to water systems tend to centre around two main factors:

1) the ability to bounce back/ return to normal, or the ability to adapt or transform in response to disturbance,
2) the types of systems to which resilience is applied to, coupled social-ecological, ecological, the built/grey infrastructure, or social systems (Rodina, 2019).

Rodina, (2019) continues to note that key discipline divides are notable within the literature as papers from the field of water engineering (identified as a large component of the sample) tend to draw on or align with engineering definitions or resilience. Such engineering notions focus on the reliability, recovery and 'bounce-back' ability, which is highlighted as a contrast to the literature which is focussed on

eco-hydrological systems that draws on resilience from an ecological and socio-ecological systems perspective. Finally, Rodina, (2019) states that the 'ecological water resilience' literature is continuing to grow, potentially showing a shift in perspective as water management literature moves to draw an understanding of resilience beyond conventional engineering approaches.

The above highlighted ambiguity and lack of clarity with regards to defining resilience in relation to water management in the academic literature, can be linked to the conceptual ambiguity of the resilience thinking that is repeatedly found throughout the literature. Such ambiguity, and at times incompatible ways of conceptualising water resilience, pose important implementation and operationalisation challenges moving forward.

With regards to the water industry in England and Wales, initially the sector approached the subject of resilience from a risk management and engineering centric perspective linked to the concept of 'building better' and creating systems that are 'fail safe'. Such an approach resulted in the industry first defining the term using an engineering theoretical underpinning, as Ofwat aligned their views with the UK Cabinet office and defined resilience as *"the ability of a system to withstand shock and continue to function"* (Cabinet Office, 2011). The reference to 'withstanding shock' indicates a bounce back, rather than bounce forward method of thinking. Following the changes made to the Water Act 2014 in which Ofwat was awarded a primary duty on resilience ('Water Act (England and Wales) 2014 c.28', 2014) an independent Task and Finish Group was commissioned to advise the regulator on what resilience meant for the wider water sector (Ofwat, 2015). This group consisted of members from across the water sector including industry, academia and regulation, and work was focussed on identifying and agreeing on ten suggestions relating to the new resilience duty. One of the central outcomes was that of the development of a resilience definition.

> *"Resilience is the ability to cope with, and recover from disruption, and anticipate trends and variability in order to maintain service for people and protect the natural environment now and in the future"* (Ofwat, 2015)

It is this definition that Ofwat adopted and continue to use. The final report that was produced by the Task and Finish Group fed into the Water 2020 (Ofwat, 2017b) document produced by Ofwat which ultimately provided the structure for Ofwat's preparations for PR19. Outputs from the Task and Finish Group highlighted occasions when a lack of definition have hindered progress around resilience in the water industry, citing Ofwat's 2011 focus groups on resilience and climate change, and customer research as part of PR14 (Ofwat, 2015). In 2017, Ofwat published a document titled 'Resilience in the Round' (Ofwat, 2017a), as part of the PR19 methodology, with the aim of providing water companies with suggestions on how they could respond to the resilience challenge. Within this document the concepts of corporate, financial and operational resilience were defined, along with arguments for the need to adopt a system thinking approach to company preparations. Although this document was produced as part of the PR19 related materials, it stated that this was not a 'rule book' (Ofwat, 2017a) and that it was instead hoped that companies use this information as food for thought. Despite the Task and Finish Group highlighting the need for the industry to 'agree on a shared definition of resilience for the sector' (Ofwat, 2015) in 2015, at the time of writing this is yet to formally happen, with Ofwat allowing individual companies to choose how they defined and understood the term 'resilience' throughout the PR19 process.

The adoption of the Task and Finish Group recommended definition by Ofwat highlights a shift away from a solely engineered focus in definition to one that incorporates and acknowledges a wider system based view. The focus on the customer (both people and environment), emphasises Ofwat's view and role as the sectors economic regulator.

2.4 Resilience and related concepts

Research and policy related to efforts focussed on building or increasing resilience traditionally imply or include the concepts of sustainability, adaptation, coping, and vulnerability. However, how the concepts are related remain the subject of debate across industry and academic fields.

2.4.1 Resilience and sustainability

The concept of resilience and the broader framework of sustainability have undoubtedly seen their share of inclusion in policy rhetoric over recent times, with both resilience and sustainability heavily involved in the future direction and operation of water sectors both globally, and locally focussed on the UK (Bissel, 2010). For many, the notion of 'resilience' can perhaps be seen as the 'new kid on the block' with relation to its relatively recent increase in popularity across academia, industry and wider society (Brown, 2015). However, when discussing resilience, it is important to first consider it within the broader framework of sustainability.

Leigh and Lee, (2019) state that sustainability is a normative concept that refers to physical and institutional practices that meets the need of the present without compromising the ability of the future. As with resilience, discussion and debate around sustainability criteria and the definition continue, with a precise definition remaining elusive (Sahely *et al*., 2005; Milman and Short, 2008). However, sustainable development and the creation of sustainable systems is fundamentally based on the achievement of a balance between environmental, economic and social objectives over dynamic time and spatial horizons (Sahely *et al*., 2005).

The sustainability paradigm therefore requires multidisciplinary action and the involvement of multiple stakeholders from all levels and areas of the system. Sustainability is now recognised as the most widely used framework in natural resource management and is often depicted as a triangular model that balances the three competing interests of society, economics and the environment. Criticism of the sustainability model is often based around the idea that it suggests a static balanced system rather than one that embodies the continuously altering and

reshaping tensions and priorities that result from both internal and external pressures (Leigh and Lee, 2019). It is therefore suggested that sustainability is better seen as a journey or trajectory rather than a fixed state (Butler and Davies, 2010; Butler *et al.*, 2014). As highlighted by Butler *et al*., (2014), the goal of a sustainable system is *"therefore to continue functioning over the long term, balancing of agreed societal goals".* Further criticism relating to sustainability and its relationship to resilience (Leigh and Lee, 2019) are again related to temporal or spatial scale. This is as at times, the objectives of resilience at one systemic level may negatively impact or affect sustainability goals at another (Chelleri *et al.*, 2015). Such criticisms have resulted in the recommendation that all resilience –based actions and interventions must also be viewed within the context of sustainability.

2.4.2 Resilience and adaptation

Definitions and applications of the term 'adaptation' within the literature vary. However, adaptation is typically considered to consist of targeted actions or adjustments that are carried out in a specific system in response to actual or anticipated threats, in order to minimise system failure and consequences (Butler *et al*., 2016). Adaptation is considered similar to that of vulnerability, in regards to the fact that increased attention has been paid to the concept due to the development of climate change research and how to facilitate human initiative to reduce the adverse impacts of climate change on socio-ecological systems (Lei *et al.*, 2014).

Again, application across many different disciplinary fields has resulted in the term having a range of diversified understandings with a general view that the key to adaptation is 'adjustments to change' in a system, regardless of the long or short term. However, Lei *et al*., (2014) questions whether or not all kinds of adjustments should be defined as adaptation, or just certain scope of them. Butler *et al*., (2016) define adaptation as;

> *"any action taken to modify specific properties of the water system to enhance its capability to maintain levels of service under varying conditions"*, where

mitigation is defined as *“any physical or non-physical action taken to reduce the frequency, magnitude or duration of a threat*”.

Hence identifying mitigation measures as those that take place before the threat or event occurs and adaptation measures as those after the threat has occurred and aimed at reducing the scale of the impacts. It is considered that the concept of adaptation highlights that instead of trying to control nature, society needs to learn to live in a way that is more compatible with the occurrence of disasters (White, 1974 cited by Lei *et al*., 2014). The concept of adaptation pairs with the developing view of systems that are ‘safe to fail’ rather than those that are ‘fail safe’.

2.4.3 Resilience and coping

Initial focus on the concept of coping with regards to resilience was centred on the ability of individuals to cope, and was of great interest to researchers aiming to identify individual and environmental protective factors underlying resilient behaviour.

The concept of coping is typically seen as any response to threats and their impacts (Kabat *et al*., 2002 cited by Butler *et al*., 2016), and is defined by Butler *et al*., (2016) as

“*any preparation or action taken to reduce the frequency, magnitude or duration of the effects of an impact on a recipient*”.

With coping measures often being temporary and only actualised when mitigation and adaptation measures have proved insufficient at ensuring compliance with the required level of system performance (Butle*r et al*., 2016). Depending on the context and system in question coping measures are often temporary solutions put in place to address and minimise the risk of specific consequences. Coping mechanisms are more likely to be concentrated on the social aspects of water sector systems, in comparison to mitigation which can at times have an engineering or physical assets focus.

2.4.4 Resilience and vulnerability

It is considered that the word vulnerability is derived from the Latin *'vulnerare'* meaning to be wounded, and in general describes the potential to be harmed, and the sensitivity to a perturbation or stress (Downing *et al*., 1997 cited by Le*i et al*., 2014). As previously highlighted in Section 2.3.3 the concepts of resilience and vulnerability are closely interlinked, with the notion of vulnerability being conceptualised in many different ways, depending on research traditions or field of application. However yet again, arguments remain as to what exactly the relationship between the two is. With most conversations centred around the notion of whether resilience is the opposite of vulnerability or alternatively related.

In recent times the concept of vulnerability has been more broadly applied to research on global environmental systems, disaster risk reduction and socio-ecological systems (Lei *et al.*, 2014). Lei *et al*., (2014) notes that the focus on vulnerability has increased with the popularity of the human dimensions of climate change research, as the focus of vulnerability has shifted from the fragility of the environmental system (i.e., physical vulnerability) to human society (i.e., social vulnerability). Lei *et al*., (2014) continues to say that it is clear that vulnerability has become an unfavourable property of SESs, which unfolds and develops in the interaction between human and natural systems and can be reduced through the enhancement of preparedness and social learning.

2.5 Systems thinking and translating resilience from the natural to the social

Increasingly the concept of resilience is seeing application in systems defined as socio-technical, socio-ecological or even socio-eco-technical systems. This is as the complexity of the world and society in which we live continues to increase. The need to acknowledge the interdependencies that exist both within and across systems has resulted in a call for a more systems based thinking approach to the management of critical infrastructure systems in particular. As boundaries of systems and

organisations in operational environments continue to blur, a more collaborative approach is increasingly suggested.

2.5.1 Socio-ecological and socio-technical systems

The notion of resilience has not only been introduced to and included in ecological and engineered systems, but also socio-technical and socio-ecological systems as the acknowledgement of the role of the 'socio', or people, in the functioning and performance of systems becomes more widely accepted. Examples of interlinked systems between humans and nature are for the majority, focussed on infrastructure, and therefore include water distribution and treatment networks as well as urban drainage.

Hosseini *et al.*, (2016) refer to the 'social domain' which focuses on the resilience capacities of individuals, groups and communities whilst (Adger, 2000, p. 347) defined social resilience as the *"ability of groups or communities to cope with external stresses and disturbances as a result of social political and environmental change"*. Potential links between social and ecological resilience through dependence on ecosystems of communities and economic activities are also discussed by (Adger, 2000) with the suggestion that societies, here referring to groups or communities, that are dependent on resources and ecosystems are less resilient.

The term 'Social-ecological systems' (SES) is used to describe such interactions between humans and nature, with the application of the term resilience to social systems a more recent concept, when compared with Holling's (1973) definition of ecological resilience. Berkes and Folke (1998) began to use the term social-ecological systems as an integrated perspective of humans-in nature and in particular highlighting the notion that *"the delineation between social and natural systems is artificial and arbitrary"* (Berkes and Folke, 1998, p.4). Here the 'social' refers to the many diverse facets of the human dimension e.g. economic, political, cultural and technological, with the 'ecological' referring to the biosphere- the global

ecological system that integrates humans, their relationships, actions and interplay with the atmosphere, water cycle and biogeochemical cycles (Folke *et al.*, 2016). The SES approach emphasises that not only are people, communities, economies and societies embedded in the biosphere, but they are also dependent on it and shaped by its ever evolving system (Folke *et al.*, 2016). SES resilience theory understands and refers to systems as non-linear and constantly changing entities and is therefore considered to be a highly relevant approach when dealing with the notion of climate change and multiple unknown variables (Meerow *et al.*, 2016). Folke, (2006) states that SES systems are based on the notion that social and ecological systems are not only highly interconnected but also mutually dependent. SES differ from traditional ecological systems with the sense that social systems have a purpose and can therefore have the ability to be designed and engineered with system performance requirements in mind (Winges *et al.*, 2009).

Folke *et al*., (2016, p. 2) define socio-ecological resilience as *"the capacity to adapt or transform in the face of change"*, with Walker *et al*., (2004, p. 1) using the definition *'the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, and identify feedbacks'*. It is the concepts of adaptation and transformation that are key to resilience in reference to SES. Here adaptability refers to human actions that sustain, innovate and aide development whilst remaining on the original pathway, where transformation is focussed on shifting development into new pathways or creating new ones (Folke *et al*., 2010, 2016; Walker *et al*., 2004). The inclusion of the concept of a system being able to absorb disturbance and reorganise whilst maintaining function by Walker *et al.*, (2004) differs slightly from previous definitions of resilience (ecological, engineering) as although the ability to absorb and reorganise relates to the characteristics, the function relates to the ability of the system to perform when under threat.

Such work on SES contributed to the formation of the Resilience Alliance, an interdisciplinary research network dedicated to resilience thinking (Walker and Salt, 2006 cited by Meerow, Newell and Stults, 2016). Members of the Resilience alliance collaborated to develop the panarchy model, aimed at understanding how complex

systems progress over time through multi-scalar adaptive cycles of destruction and reorganisation (Folke *et al.*, 2002; cited by Meerow, Newell and Stults, 2016). This work resulted in extending Holling's, (1973) definition of resilience from a measurable and descriptive concept to a *'way of thinking'* (Folke, 2006 , p. 260; cited by Meerow, Newell and Stults, 2016).

A focus on the capacity of the system as well as the need for adaptation or its adaptability appear throughout, and are vital components of the definitions of resilience related to social systems, as highlighted by both of the Folke *et al.*, (2016) and Walker *et al.*, (2004) definitions. Folke *et al.*, (2002) state that resilience in the context of SES is related to three main factors:

> *"i) the magnitude of shock that the system can absorb and remain within a given state*
>
> *ii) the degree to which the system is capable of self- organisation*
>
> *iii) the degree to which the system can build capacity for learning and adaptation*" (Folke *et al*., 2002, p. 438).

These three factors are centred on the adaptive capacity of the system and its ability to cope with shocks and stresses. Folke *et al.*, (2002) discuss the constantly changing nature of SES and their inherent adaptation and learning processes, which contributes to their ability to respond to and undergo both gradual change and drastic shifts. Resilience building within SES requires an understanding of the ecosystems in question and the ability to incorporate knowledge of local users. Folke *et al.*, (2002) states that ecological ignorance and rigid governance and management structures, erode SES resilience and promote collapse of the system. The resilience of SES is therefore dependent on the capacity of the system to continually adapt to changing situations and scenarios.

In comparison to SES, socio-technical systems refer to an approach which considers the human, social, organisational and technical factors in the design and operation of systems. The underlying premise of socio -technical systems is based on the thinking that the system design should be a process that includes both social and

technical factors that influence the functionality, performance and usage of systems (Baxter and Sommerville, 2011). By adopting socio-technical approaches to both the design and management of systems it is thought that not only will it reduce the risk of systems not making their expected contribution to the goals of the organisation, but will also ensure that systems are designed to consider the complex relationships within the organisation, e.g. the people responsible for executing business processes and the systems that support the processes (Norman, 1993 and Goguen, 1999 cited by Baxter and Sommerville, 2011). Bell, Chilvers and Hillier, (2011) suggest that by understanding engineering as a socio-technical practice, engineering can provide a more effective contribution to sustainability than conventional accounts of engineering as a purely technical undertaking.

The field of resilience engineering, which developed from a focus on safety, highlight the accident at the Three Mile Island nuclear power plant in 1979, as an initial cause for change in focus from technology alone to human performance, when looking at ways accidents could happen and systems could either fail or slip in performance (Hollnagel, 2012). At this time existing safety practices required the probability of technical failure or malfunction to be calculated which subsequently resulted in numerous proposals on how to also effectively calculate human error (Hollnagel, 2012). This resulted in the creation and indeed application of, multiple methods aimed at calculating probabilities of human error, including first and second generation Human Reliability Assessment (HRA), and the effects human error would have on system performance, or in this case more specifically accident rates. Hollnagel, (2012) states that a similar transition occurred following the disaster at Chernobyl, and the loss of the challenger space shuttle in 1986, where the focus again shifted from technical and human error to also including the organisation as a whole and organisational error probability in order to be able to fully understand why the incidents occurred. Such changes in approach emphasise the linkages between, and roles that humans play, in the functioning and performance of socio-technical systems.

Hosseini *et al.*, (2016) refer to infrastructure systems, such as water distribution, nuclear power plants and transportation systems, as a subdomain of both the

engineering and social domains. This is due to the construction and restoration of infrastructure systems requiring a base in engineering knowledge (engineering domain) and the ability of a lack of resilience to lead to adverse impacts on communities.

Infrastructure systems are examples of socio-technical systems that require both human and social factors to ensure the required level of performance is met. However, recognising interdependencies amongst different forms of infrastructure systems is also critical for effective planning and operation. Acknowledgement that the resilience of one system can greatly impact the resilience of others is critical to the operation and functioning of critical systems (Hosseini *et al.*, 2016). Here the relationships between engineering and social subdomains are evident as the performance of physical engineering systems is measured in terms of societal impact. The management of such social-ecological and social-technical systems and their subsequent differing levels of resilience are hugely applicable to water systems and the water sector on as a whole.

2.5.2 Translating the natural to the social

Davoudi *et al*., (2012b) and Davoudi (2018) state that the extension of resilience thinking beyond natural and physical systems to the social is conceptually problematic and at times normatively contested. Davoudi *et al*., (2012) highlights four critical issues that warrant particular attention when trying to translate resilience thinking from the natural to the social world. The first relates to the intentionality of human actions and allowing for the ability of human intervention to break cycles of adaptation. The concept of self- organisation is also related to intentionality, with self-organisation considered inherent in resilience thinking. Davoudi *et al.*, (2012) argues that when this is translated into the social sphere it becomes highly charged with ideological overtones as it refers to the notion and need for self-reliance. An example provided by Davoudi *et al*., (2012) notes that a Department of Business Innovation and Skills (BIS) supported report on community resilience argued that their,

> *"system dynamic diagram shows that if the Government takes greater responsibility for risks in the community, it may feel under pressure to take increasingly more responsibility, thereby eroding community resilience"* (RRAC, 2009, p. 6, cited by Davoudi et al., 2012).

Here Davoudi warns that although the existence of engaged social networks help foster adaptive capacity, thus contributing towards system resilience, it is a not a substitute for responsive and accountable governance.

The second critical issue is related to the outcome or purpose of resilience, with the question commonly posed as 'resilience of what to what?'. Resilience of ecological systems typically identify the desirable outcome of resilience as sustainability, however Davoudi *et al*., (2012) argues that in the social context, defining what is desirable is always tied to normative judgements. This is as often certain outcomes are considered "natural" or desirable, whilst others are dismissed as a lack of resilience. Therefore, as the outcomes depart from the those perceived as desirable, an alternative outcome (which could still be positive) may not be seen as a sign of resilience.

The third issue focuses on defining a systems boundary, again relating to the question of "resilience of what to what?". Davoudi *et al*., 2012 states that in the social context such a bounded approach can lead to exclusionary practices. With the fourth issue relating to power and politics and the conflict that arises over the answers to the question "resilience of what to what?". Here application of resilience to ecological systems differs to social as in ecology, it is considered that ecologists subscribe to the notion that *"There are in nature no rewards or punishments, just consequences"* (Westley *et al*., 2009 p.103 cited by Davoudi *et al*., 2012 p.306). This approach may be true, however in society there are always rewards and punishments meaning that resilience for some people or places may result in the loss of resilience for others. Davoudi *et al*., (2012, page. 306) concludes that *"in the social context we cannot consider resilience without paying attention to issues of justice and fairness in terms of both the procedures for decision-making and the distribution of burdens and benefits"*.

2.6 The resilience engineering approach

Over recent years resilience engineering (RE) has been increasingly advocated as an alternative form of 'safe' management for complex socio-technical systems (Righi *et al.*, 2015). In the wake of *"multiple major mishaps"* (Woods and Wreathall, 2003, p.1), the need for organisations to equip their engineering processes and capability to address both human and organisational risk factors was identified (Woods and Wreathall, 2003). Woods, (2003) state that RE *"uses the insights from research on failures in complex systems, including organisational contributors to risk, and the factors that affect human performance to provide system engineering tools to manage risks proactively"* (cited by Righi *et al*., 2015, p.143). RE is based on the assumption that resilience can be engineered into complex socio-technical systems as a mechanism for supporting the use of adaptive capacity (Righi *et al.*, 2015). RE emerged as an alternative to error tabulations and as a new field aimed at enhancing the ability for organisations to monitor risks and proactively target safety investments independent of ongoing production and economic pressures (Woods and Wreathall, 2003). Hollnagel *et al*., (2006) suggest that 'failure' within resilience engineering is the result of the adaptations necessary to cope with the complexity of the real world rather than a breakdown, malfunction or error, and that 'success' is based on an organisations ability to anticipate the changing shape of risk before failures and harm occur.

Woods and Wreathall, (2003) trace the origins of resilience engineering back to researchers from multiple different disciplinary backgrounds investigating the factors behind the notion of 'human error', how systems fail, and how people in various roles and their actions contributed to either the success or failure of systems. Woods and Wreathall (2003) note that as people become aware of potential paths to failure the development of failure sensitive strategies to forestall these possibilities occurs, and when failure occurs against the background of usual success, multiple contributors were found to be necessary but only jointly sufficient. Reason, (1997) cited by

Woods and Wreathall (2003, p.2) describes such contributors as '*latent conditions'* which arise due to:

1. Finite resources- lack of adequate reviews of safety and system performance, well qualified systems engineers etc.
2. Uncertainty- in systems performance, environment, and design processes
3. Change- which is a constant as new capabilities are exploited by leaders.

The result from such factors identified a process in which *"a drift towards failure precedes major events as planed defences erode in the face of production pressures and change"* (Woods and Wreathall, 2003,p. 2). Hence, it was identified that failure arises from systematic and predictable organisational factors at work, rather than simple erratic behaviours by individuals (Woods and Wreathall, 2003).

Righi *et al.*, (2015) conducted a systematic review of resilience engineering literature in which they identified six key research areas. Such areas are; theory of resilience, identification and classification of resilience, safety management tools, analysis of accidents, risk assessment, and training. Results from the study highlight the linkages between resilience engineering and other related disciplines including systems engineering, Normal Accidents Theory (NAT) and High Reliability Organisations (HRO). Links between RE and complexity with regards to how guidelines used to create and foster a resilient environment interact with other aspects and guidelines on the management of such complex socio-technical systems are also highlighted (Righi *et al.*, 2015). Research into HRO shows that safety is created by anticipating and planning for unexpected evets and future surprises (Woods and Wreathall, 2003). Here organisations do not take past successes as a reason for inflated confidence in their systems, but instead continue to invest in safety and learning activities which are dependent on the open flow of information on the potential of failure, in order to guide constructive change (Woods and Wreathall, 2003).

With relation to defining the term resilience Righi *et al*, (2015) found that the approach used within the recently established field of RE has more similarities to the view taken within psychology, rather than that of ecology or engineering. Righi *et al*, (2015) cites studies conducted by Le Coze and Capo, (2006) and Specht and Poumadere, (2006) which concluded that *"both RE and psychology value the role of past events as a bias for resilience"* (Righi *et al*., 2015, p. 146). The study also found that the majority of RE based academic literature is characterised by the development of guidelines, frameworks and methods aimed at the identification and classification of resilience (Righi *et al.*, 2015).

RE has been found to focus on how performance occurs within complex socio-technical systems rather than the properties associated with management and evaluation practices for the management of resilience. Here the safety of a system or organisation is viewed as a process of its performance. Hollnagel, (2011b) argues that resilience refers to what the system 'does' rather than what it 'has'. It is simply stated that *"A system cannot **be** resilient, but a system can **have** a potential for resilient performance"* (Hollnagel, 2011b, p.1). He continues to state that as 'resilience' is multifaceted and therefore cannot be described by a single dimension, there is *"no quantity, amount or level of resilience"* (Hollnagel, 2011b, p.5). This view therefore results in the notion that the resilience of a system is not something that can be quantified and measured but is instead a characteristic that contributes to the potential for system performance. Focussing on the notion of resilience being something that an organisation/system 'does' rather than something they 'have', Hollnagel, (2011b) suggests four essential abilities of resilience that are believed to be required for a resilient organisation. The four abilities include; the ability to respond, the ability to monitor, the ability to anticipate, and the ability to learn (Hollnagel, 2010).

Research conducted by Woods and Wreathall, (2003) into the need for RE ultimately found that success relates to organisations, groups and individuals who produce resilient systems that are able to recognise and adapt to change, with the measure of success for groups and organisations held in their ability to anticipate the

changing shape of risk before failure occurs (Woods, 2000 cited by Woods and Wreathall 2003).

2.7 Organisational resilience

Along with its application in SES and urban systems such as cities, the use of the term ‘resilience’ in other socially dominated systems and sectors has also increased. As the world around us continues to change, organisations must also continually adapt in order to remain competitive within hugely uncertain environments (Burnard and Bhamra, 2011). The concept of organisational resilience is much more recent, and work carried out by Vogus and Sutcliffe, (2007) outlines the key notions and characteristics of the theory of organisational resilience. Vogus and Sutcliffe, (2007) argue that the creation of a theory of organisational resilience would not only provide insight into how organisations, and the individuals and units within them, continue to achieve desirable outcomes amidst adversity, strain and barriers to adaptation or development, but would also help to promote *“a new way of seeing by arguing that organisations are more efficacious than some deterministic perspectives in organisation theory allow”* (Vogus & Sutcliffe, 2007, p. 3418). Dalziell and Mcmanus, (2004) state that there is a need to critically evaluate the consequences that hazards may have on organisations, however the complexity of organisations and the ever changing context within which they operate poses a significant challenge to achieving this goal.

Questions around why some organisations crumble when faced with high levels of ongoing strain, or unanticipated disruptive events but others thrive and succeed must be answered in order to fully understand the notion of organisational resilience, it’s characteristics and requirements. Dalziell and Mcmanus, (2004) suggest the use of systems analysis in order to understand the complex interactions and multiple feedback loops that exist within organisations. Here by viewing organisations as active and complex systems the purpose and performance of such systems/ organisations, as well as their characteristics and properties, can be analysed and measured.

Woods and Wreathall, (2003) interchange the use of the terms ‘resilience engineering’ and ‘organisational resilience’ with the view that resilience must be engineered into a system in order for the organisation to be considered as resilient. Such linkages between resilience engineering and organisational resilience are necessary, in order to understand and improve levels of resilience and performance within complex systems referred to as organisations.

Resilient Organisations, (2018), an organisational resilience consulting team, refer to three interdependent attributes; Leadership & Culture, Change Ready and Networks & Relationships, and thirteen indicators of resilience. They argue that the thirteen indicators of resilience help build business as usual and contribute to a robust and agile response and recovery from crises (Resilient Organisations, 2018). The group also describe and refer to resilience as a strategic capability for organisations, something that has the potential and ability to turn crises into a source of strategic opportunity for organisations, as well as the notion that ‘no organisation is an island’ (Resilient Organisations, 2018). This idea relates to the wider concept of an ecological like system that many organisations are part of, where resilience of one organisation is not only dependent upon its own staff members and individuals, but also other organisations and systems, customers, suppliers, regulators, etc., (Resilient Organisations, 2018). This concept of the need for resilience between multiple organisations and systems at differing levels relates to the notions of supply chain and infrastructure resilience.

Supply chains are extremely complex networks of enterprises that continually experience turbulence, creating the potential for unpredictable disruptions (Pettit *et al.*, 2010). Such disruptions mean that in 2007, FM Global cited by Pettit *et al.,* (2010. p.1) reported that many company executives *“identified supply chain risk as the highest risk to their firms”*. Traditional risk management techniques have been identified as lacking in their ability to assess and understand the complexities and interdependencies that exist within supply chains and the threats they face. The outbreak of the COVID-19 pandemic in 2020, highlighted the brittleness and lack of

operational agility possessed by global supply chains (Sarkis, 2021), and further emphasised the complexities that exist within the current supply chain systems.

It is for this reason that many supply chain researchers are thought to be beginning to understand the need for, and value of the concept of resilience over risk management (Pettit *et al.*, 2010) in order to address the gaps identified.

In regards to supply chain resilience, Pettit *et al.*, (2010) describe resilience as *"the capacity for an enterprise to survive, adapt, and grow in the face of turbulent change"* (Fiksel, 2006 cited by Pettit *et al.*, 2010, p.1). The interconnected system and interdependence of organisations and supply chains highlights the need for resilience to exist at all levels of a system, organisation, network before a singular organisation and or system can be considered resilient.

2.8 Operationalisation of resilience

Although academic interest in the concept of resilience has been steadily increasing over recent years, the conceptualisation of the complex construct with relation to organisations and resilient performance is still in its infancy. With many studies continuing to merely point out organisational characteristics that appear to be relevant to resilience. Such an approach has resulted in resilience simply being treat as an outcome, which is highlighted when organisations or systems perform well during a crisis or interruption (Duchek, 2019). Such issues surrounding definition, metrics and whether resilience is present or absent continue to cloud the resilience literature. This has resulted in relatively few studies focussed on how resilience based actions can actually be implemented across organisations and systems (Johannessen and Wamsler, 2017). Rodina, (2018) states that the issue goes further than this and that many resilience principles such as flexibility, interconnectedness and social learning are still not well articulated, which has in turn resulted in poor operationalisation in relation to specific design, planning and governance practices across contexts and domains. Harris *et al.*, (2017) suggest the need for the development of the concept of 'negotiated resilience', to highlight the complexities and procedural dimensions of the implementation and operationalisation of

resilience. Asadzadeh *et al.*, (2017) state that not only does considerable disagreement remain around resilience as a concept in general, but also on mechanisms for operationalising it as a concept. It is how such resilience theory and related principles can be mobilised and applied within organisations that is key to the creation of resilient system performance.

2.8.1 Operationalisation of resilience and the water sector

As outlined earlier in this chapter, the notion of resilience has seen a recent increase in popularity in the UK water sector over recent years, however issues around how tangible actions can be implemented at the operational level remain. This section aims to further explore barriers to operationalisation of resilience within the UK water sector.

Lack of definition

Section 2.4.3 highlights the issues surrounding the lack of clarity and singular definition of the term resilience for the UK water sector. Ofwat's failure to insist on the use of a singular definition by companies as part of the PR19 process, despite recommendations from the Task and Finish Group emphasise the lack of clarity facing the UK water sector regarding a resilience definition.

Metrics for the water sector

The measurement of resilience, and applying a scalable value or quantity to its presence in a system can be found throughout the literature, and after definition of the term is one of the most popular areas of study (Cumming *et al.*, 2005; Hosseini *et al.*, 2016; Lee *et al.*, 2013; Schipper and Langston, 2015). This is as metrics, much like definitions, span multiple fields and sectors and operate at varying scales and levels of complexity.

As part of its list of ten recommendations made in 2015 for the advancement of resilience in the water sector in England and Wales, the Resilience Task and Finish Group suggested 'developing benchmarking standards and metrics' (Ofwat, 2015). The group stated that both Ofwat and water companies need to develop metrics that are capable of *"comparing resilience, reflecting customer views, local context, the environment and company ownership of plans"* (Ofwat, 2015). With the report also suggesting that companies should report against a set of resilience criteria, which should be qualitative, and ensures that all company boards have properly assessed resilience in a way that goes beyond their existing risk register. Here the suggestion to measure resilience via qualitative methods differs from the traditional engineering view of resilience typically adopted by the water sector, in which quantitative methods are more commonly adopted and promoted. As part of the PR19 process, Ofwat suggested the use of metrics and a standard method of reporting to help aid comparison between companies (Ofwat, 2017b).

More generally the use of metrics and indicators has become standard across all levels of government and organisations as a way to simplify decision making, compare performance and track progress. The use of sustainability indicators in particular has increased over recent years as the demand for unbiased metrics for rationale decision making and the ability to track and evaluate large scale trends increase (Milman and Short, 2008). As with sustainability the interest in resilience metrics has also increased, as system operators and managers search for indicators of the resilience of their system or their presumed ability to perform whilst under stress, along with the ability to compare types of system.

The term 'indicator' is defined by the Oxford English Dictionary as something that *"points out, or directs attention to, something"* (OED Online, 2019a), with the term 'metric' defined as *"a system or standard of measurement: a criterion or set of criteria stated in quantifiable terms*" (OED Online, 2019b). Typically, a number of metrics contribute to overall indicators, with the primary goal of indicators considered to link cause with outcome (Milman and Short, 2008). Causal models are considered to provide the greatest insight into relationships between indicators and outcomes. However the complexity of distinguishing operating conditions from stresses,

determining relationships and measuring the capacity of a system to response is highly complex (Milman and Short, 2008). Yet it is the system's capacity to respond and adapt that remains the most likely to lead to resilience, and therefore indicators that highlight and indicate such an ability are considered most likely to reflect the level of resilience present within a system.

Submissions to Ofwat of water company business plans for the PR19 process indicate the current status, approach and understanding of resilience metrics within the industry. Multiple companies approached metrics from a quantitative traditional risk management-based view. In which first possible threats or shocks and stresses are identified, followed by measuring how current systems would respond to them pre and post identified interventions. An example of such an approach can be seen in the resilience metrics methodology prepared for Untied Utilities by Arcadis (Arcadis, 2017), for their PR19 submission. Ofwat considered this an example of 'good practice' with the submissions awarded a B grade for all three resilience test areas (Ofwat, 2019).

Acknowledging the socio- technical

As discussed in Section 2.5 socio-ecological and socio-ecological-technical systems are extremely complex with whole system performance depending on a precise interplay of all aspects involved. It is therefore necessary to acknowledge all parts of the system equally. Traditional focus on risk management of the physical engineered systems that are required for the collection, treatment and distribution of water and wastewater, as well as the more recent emphasis on the status of ecological systems, has resulted in the social aspect of system performance and management typically being viewed as a lesser addition.

The answer to the question 'resilience for who, and to what?' has up until now rarely been addressed through changes made to the social aspects of the system. Instead, focus is often placed on disturbances by exogenous forces that underplay the internal social dynamics of the system in question. With many sectors, including the

water industry, focussing on optimisation of engineered parts of the systems through introduction and increased reliance on automated systems. Such increased reliance and use of automated technology further increases levels of complexity and interconnectedness in already complex systems, with many technological advances bringing new security threats and increasing levels of system vulnerability (Letwin, 2020).

As part of the 'Resilience in the Round' documentation from Ofwat, operational resilience is defined as;

> *"the ability of an organisation's infrastructure, and the skills to run that infrastructure, to avoid, cope with and recover from, disruption in its performance"* (Ofwat, 2017a)

The report (Resilience in the Round) goes on to document several examples of how resilience can be improved at a corporate financial and operational scale. However, the specific roles or effects that individuals or social groups and networks have on the overall performance, and therefore resilience of the system, are not referenced or recognised. Although reference is made throughout to customers and the value that resilient systems will give to customers, there is no specific reference to the sector's workforce. This is in contrast to research conducted by Baker *et al*., (2018), which focussed on resilience learning for water sector culture change in the UK, and highlighted the threat that poor leadership and changes in staff profiles can have on the overall resilience of the system or sector.

Within the water sector there is increasing acceptance of resilience being viewed not as a means of controlling the conditions or threats that have the potential to affect a system, but instead as the ability of the system to respond to change and manage performance based on the scenario in which it is operating (Butler *et al*., 2016). Research that has been conducted in the field of community resilience analyses issues of scale within systems and communities, which looks at stakeholders at all levels and the effect they have on the performance of a system (Wilson, 2012). This work emphasises that especially in complex systems, it is not solely external forces

that pose a risk to performance and function but also internal forces. Wilson, (2012) emphasises the need to take into account that communities are comprised of individuals, household and stakeholder groups, with each having their own resilience pathways, that may differ to the community in which they live. Such observations are necessary when normative questions such as ‘who is defining and measuring resilience?’ and ‘how the data will be measured?’ come into play. This is so that it is made clear that methodologies to assess resilience are as inclusive as possible of different stakeholders views that exist within the community, organisation or system, if both communities and organisations are to understand their resilience strengths and weaknesses (Lee *et al.*, 2013). Wilson theorises that the implementation of resilience pathways can only find its most direct expression at the individual/ household level, as it is only the most local level that the outcomes of policy and higher-level decision making can be turned into action within tangible effects. Such work indicates that for the concept of resilience to turn from a theorised academic principle to a tangible operational method in the water sector, specific attention must be made at the local operational scale, and more specifically with the people and the networks that exist at such scale.

2.9 Chapter summary

This chapter has sought to investigate Objective 1 and Objective 2 by exploring the current status of resilience in the UK water sector, as well as to understand the concept of resilience within the context of the UK water sector.

- The review of the literature highlights the current status of water governance in the UK and recent changes to policy and legislation that have further increased the requirement for resilience and related measures within the sector.
- The exact definition of resilience was found to be one of a contentious issue, with how you define resilience dependent upon which academic field, or school of thought the system in question is most closely related too. The review emphasises that despite recommendations from the Task and Finish Group (Ofwat, 2015), one single definition of resilience for the water sector still does

not exist. How resilience links to related concepts was also identified through the review.

- The rise in systems thinking approaches was identified as a result of the increasing complexity of critical infrastructure systems that house increasing interdependencies. The roles that humans play and the relationship between engineering and social subdomains was identified as critical areas to focus on if the functioning and performance of socio-technical and socio-ecological-technical systems is to meet required targets.
- With regards to the operationalisation of resilience it was identified that a focus on the definition of resilience and development of metrics to measure if resilience is present or absent, continue to cloud the literature. This along with the understanding that many decision-makers consider the content of existing resilience frameworks to be too abstract and far from daily activity, has resulted in poor levels of operationalisation of resilience across the UK water sector.

Chapter 3: Research Design and Methodology

3.1 Introduction

The literature review (Chapter 2) explored the theoretical understanding of the concept of resilience, and the current level of resilience understanding that exists within the UK water sector. Here it was recognised that despite the rise in popularity of the term in both sector focussed policy and legislation, as well as wider society, a broad understanding and wide scale operationalisation within the UK water sector is yet to occur. Failure to fully utilise resilience associated measures not only risks failure of the sector to comply with national policy (Water Act 2014), but also develop and maintain systems capable of responding to and managing an ever-increasing number of threats. The purpose of this chapter is to therefore provide a description of the methodological approaches employed in fulfilling the aims and objectives of this research.

This chapter covers:

- Case study focussed research
- Research design
- Mixed methods
- Quantitative research
- Qualitative research
- Methodological design
- Ethical considerations
- Chapter summary

3.2 Case study- Northumbrian Water

This research has taken a case study approach with the aim of generating an in-depth understanding of a complex issue through use in a real-life context. The UK water sector has provided the focus for this research with project sponsor,

Northumbrian Water (NW), providing the case study with access to operational staff members and industry insight.

Northumbrian Water Limited (NWL) is the registered company that trades as Northumbrian Water (NW) in the North East of England, where it provides supply of potable and raw water along with the collection, treatment and disposal of sewerage and sewage sludge. In the South East of England NWL trades as ‘Essex and Suffolk Water’ (ESW) where only water services are supplied. In total, NWL employs just under 3,000 people, supplying services to 2.7 million people in the North East and 1.8 million in the South East (NWG, 2021).

NWL is a wholly owned subsidiary of Northumbrian Water Group Limited (NWGL) a company registered in England and Wales and is a member of Northumbrian Water Group (NWG). The ultimate parent company and controlling party of NWL and its subsidiaries is CK Hutchinson Holdings Limited which is a company listed on the Stock Exchange of Hong Kong Limited.

3.3 Research design

This research has applied both consultative and participatory methods of engagement with members of the UK water sector workforce in order to meet the research aims and objectives. Both qualitative and quantitative research methods have been used to create the mixed methods research design. A questionnaire, semi- structured interviews and focus groups were undertaken with members of the Northumbrian Water (NW) workforce and wider UK water sector for data collection. As the researcher was based with the industrial sponsor (NW) for 80% of their time, the opportunity to interact with the workforce and learn more about how the organisation operated on a daily basis, as well as in emergency situations, was provided on multiple occasions.

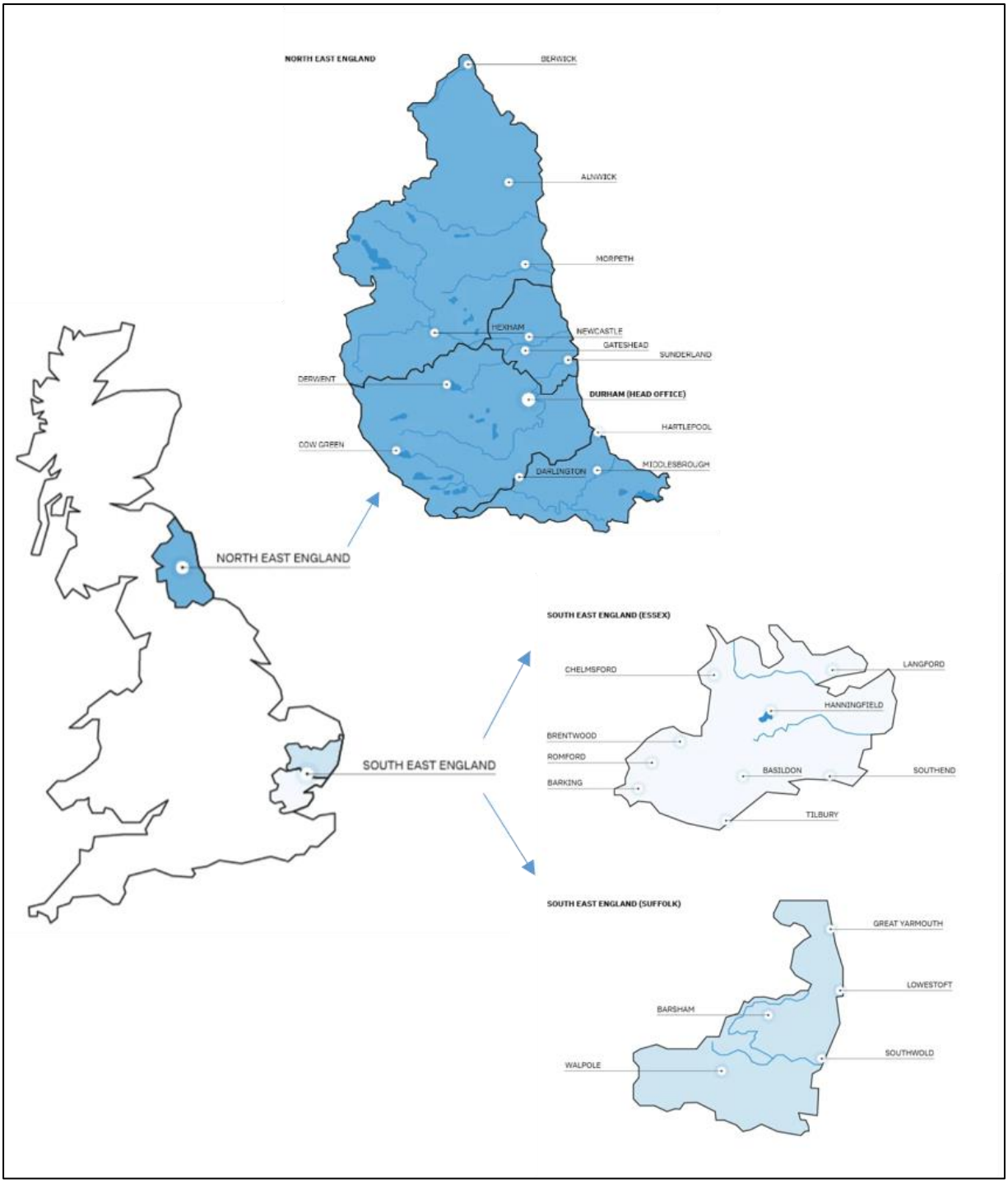


Figure 3.1 NWL operating area (Adapted from NWG, 2021)

Table 3.1 presents each of the research objectives and research methods used to achieve them. Each form of data collection used in this research is further outlined in the remainder of this chapter.

Table 3.1 Research objectives and methods of assessment.

Number	Objective	Semi-structured interviews	Focus groups	Questionnaire survey	Literature Review
1.	To explore the current status of 'resilience' in the UK water sector			X	X
2.	To understand the concept of resilience within the context of the UK water sector			X	X
3.	Investigate how an existing resilience framework can be used to assess organisational resilience within the UK water sector.	X			
4.	To develop a resilience based application for use in the UK water sector.		X		
5.	To develop policy and practice recommendations to enhance the successful operationalisation of resilience within the UK water sector.	X			

3.4 Mixed methods research

A mixed methods approach to data collection was identified for this research due to the complex and interdisciplinary nature of the research questions. Mixed methods based research purposefully combines qualitative and quantitative data collection within the same methodological design, with the aim of providing researchers with an

opportunity to view phenomena from alternative perspectives through more diverse research lenses (Shorten and Smith, 2017).

Mixed methods research is often employed in order to gain a better understanding of connections or contradictions between qualitative or quantitative data, as well as facilitating different avenues that enrich evidence whilst allowing deeper questions to be asked and answered (Shorten and Smith, 2017). Traditionally mixed methods research is applied in order to develop a more complete understanding of the wider context of the research (Greene *et al.*, 1989).

Supporters of mixed methods argue that such an approach can help overcome weaknesses of a single qualitative or quantitative method (Greene and Curucelli, 1997; Johnson and Onwuegbuzie, 2004). However quantitative and qualitative purists view these two approaches to be based on incompatible premises and techniques, arguing that mixed methods is neither a valuable or meaningful option to pursue (Guba,1990 cited by Chen, 2006). More recent developments in the philosophy of science argue that the two traditions should not have separate-but-equal status and should instead interact (Olsen, 2016). Symonds and Gorard, (2009) suggest that as a label grown out of two already existing stereotypes (quantitative- anything that involved numbers, and qualitative- anything else), that mixed methods is in danger of acting against its own aim inhibiting new growth in research. It is therefore suggested that the rationale for mixed methods research dictates that the qualitative and quantitative paradigms co-exist into a single study under a new paradigm based on the philosophy of pragmatism (Symonds and Gorard, 2009).

Research conducted by Greene *et al.,* (1989) identified five mixed method purposes generated from a theoretical review (Table 3.2). The five purposes outlines the differences in approach and design characteristics that are available to researchers, when conducting mixed methods based research.

Table 3.2 Purposes for mixed method evaluation designs Adapted from (Greene *et al*., 1989)

Purpose	**Definition**	**Rationale**
Triangulation	Seeks convergence, corroboration, correspondence of results from the different methods.	To increase the validity of constructs and inquiry results by counteracting or maximizing the heterogeneity of irrelevant sources of variance attributable especially to inherent method bias but also to inquirer bias, bias of substantive theory, biases of inquiry context.
Complementarity	Seeks elaboration, enhancement, illustration, clarification of the results from one method with the results from the other method.	To increase the interpretability, meaningfulness, and validity of constructs and inquiry results by both capitalizing on inherent method strengths and counteracting inherent biases in methods and other sources.
Development	Seeks to use the results from one method to help develop or inform the other method, where development is broadly construed to include sampling and implementation, as well as measurement decisions.	To increase the validity of constructs and inquiry results by capitalizing on inherent method strengths.
Initiation	Seeks the discovery of paradox and contradiction, new perspectives of frameworks, the recasting of questions or results from one method with questions or results from the other method.	To increase the breadth and depth of inquiry results and interpretations by analysing them from the different perspectives of different methods and paradigms.
Expansion	Seeks to extend the breadth and range of inquiry by using different methods for different inquiry components.	To increase the scope of inquiry by selecting the methods most appropriate for multiple inquiry components.

The limitations of quantitative and qualitative are also highlighted within the literature with Johnson and Onwuegbuzie, (2004) suggesting that an understanding of the strengths and weaknesses of both, provides the researcher with an opportunity to combine strategies and produce the best outcomes through the use of a mixed

methods strategy. This is as although quantitative methods have an advantage of focussing on the macro-scale, qualitative methods provide the ability to focus on the micro-scale issues. Here, rather than focussing on the generalisation of large populations, qualitative studies offer the opportunity to view a smaller window-like view on the situation or phenomenon being studied. As Robson, (2002) states a combination of qualitative and quantitative methods then help integrate findings on both the macro and micro scales.

Employing a mix of both quantitative and qualitative research provided the best approach to investigate the research objectives which lead to the overall project aim. The rationale for the use of a mixed methods approach was to integrate both representative and explanatory results in order to develop a strategy for the further operationalisation of resilience in the UK water sector.

3.5 Quantitative research

Quantitative research methods comprise of the process of collecting data, analysing data and presenting the results, and refers to counts and measures of things (Lune and Berg, 2016). For qualitative data collection, this is usually conducted via pre-determined methods such as questionnaires which allow for a large number of participants and for statistical analysis to be carried out on the results.

Cohen,(1980) cited by Sukamolson, (2010) highlights that quantitative research is defined as social research that employs empirical methods and empirical statements. With Cohen, (1980) stating that an empirical statement relates to a descriptive statement about what is the case in the real world, opposed to what ought to be the case.

Within this research quantitative research methods were employed through a pilot questionnaire survey designed to help gain an understanding on the level of knowledge and awareness on the concept of resilience that existed within the NW workforce before the qualitative research began. Cross sectional surveys involve the

collection of data at a single point in time from a sample drawn from a specified population (Krosnick *et al.*, 2014).

A questionnaire survey was selected as the main approach for quantitative data collection for the following reasons:

1. Questionnaires provide a quick method of collecting large amounts of data about a population within a given framework.
2. Questionnaire surveys are well suited to being administered to a representative sample, therefore allowing generalisations to be made about the targeted population.
3. The development of online survey platforms has resulted in a more efficient and easier data collection process for both the researcher and participant. This was especially necessary during the COVID-19 pandemic and the mass move to working from home.

3.6 Qualitative research design

Qualitative research refers to the meanings, concepts, definitions, characteristics, metaphor, symbols and descriptions of things (Lune and Berg, 2016). Qualitative research seeks answers by examining various social settings as well as the groups or individuals that inhabit such settings (Lune and Berg, 2016).

Qualitative research based studies can employ several different types of interviews with the most popular being that of semi-structured interviews and focus groups (Giacomini and Cook, 2000). Both in depth, semi structured interviews and focus groups were employed in this research project. Individual semi-structured interviews were facilitated by use of an interview guide, which contained a list of questions, follow up questions and notes. Both interviews and focus groups were conducted with water sector employees. A breakdown of how each form of qualitative data was collected for this research is further outlined below.

3.7 Methodological design

The research methodology consists of four stages (Figure 3.2), each of which relate to the objectives outlined in Chapter 1. The first stage is focussed on a literature review and pilot study questionnaire involving members of NW workforce, to explore the current status of resilience in the UK water sector and to understand how resilience epistemologies can be operationalised.

The second stage is focused on semi-structured interviews with UK water sector executives to investigate how an existing resilience framework can be used to assess organisational resilience within the UK water sector.

Stage 3 comprises of the development of an online resilience based application for use in the UK water sector. A combination of online and in person focus groups were used to co-develop the tool with members of NW operational teams.

Stage 4 focussed on the development of a strategy for implementation of policy and practice recommendations for the operationalisation of resilience in the UK water sector. Results from semi-structured interviews were used to inform and shape the recommended strategy for operationalisation.

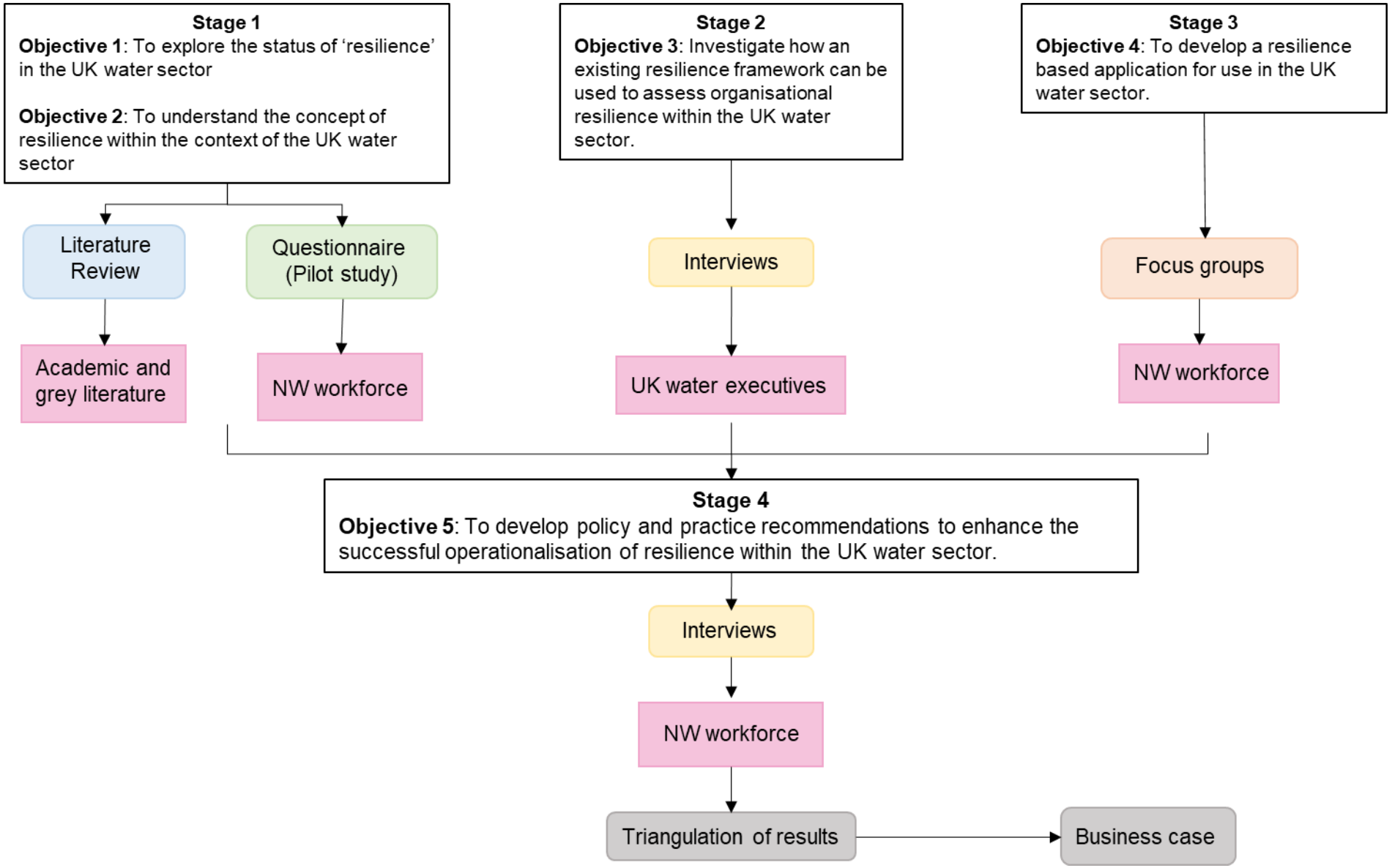


Figure 3.2 Research Methodology

3.7.1 Research methods used to investigate how an existing resilience framework can be used to assess organisational resilience within the UK water sector (Objective 3).

Interview design

A total of eleven semi-structured interviews were conducted with UK water sector executives from ten different organisations, as one company provided two participants, to further investigate the organisational and operational response and resilience to COVID-19 by UK based WASCs. A semi-structured approach was adopted in order to facilitate more open discussion around the research topic, whilst also maintaining a clear structure across the eleven interviews.

An interview transcript (Table 3.3) was developed based on the four interventions identified within the Safe & SuRe framework (Butler *et al*., 2016). The transcript consisted of four parts:

- **Mitigation**- any physical or non-physical actions taken to reduce the frequency, magnitude or duration of a pandemic.
- **Adaptation**- any action taken to modify specific properties of the water system or organisation to enhance its capability to maintain levels of service under new operating conditions.
- **Coping**- any preparation or action taken to reduce the frequency, magnitude or duration of the effects of an impact on a recipient.
- **Learning**- how experience and new knowledge gained has been embedded in best practice.

The questions explored: pandemic preparedness, adaptations post pandemic emergence, other large scale threats during the period that required further intervention, unanticipated challenges, effectiveness of coping mechanisms, reflections on measures taken, and lessons learnt.

Table 3.3 Interview transcript for semi-structured interviews

Question number	Intervention	Semi-structured Interview Question	Follow up questions	Notes
1	Mitigation	At a strategic level, prior to February 2020,had your organisation done anything to prepare for a pandemic?	Has the organisation considered such threats in previous planning, with regards to the wider organisation and on the ground operations? What were considered to be the main threats to the organisation before the pandemic and what became the main threats after? How did pandemic awareness rank against other threats? If not, do you see a change for that in the future?	For example, Number 1 or highest scoring on impact and likelihood on UK governments risk register for 2017 (Cabinet Office, 2017). Looking at the concept of organisation and operational risks this covers both? (McDonald, Edited by Hollnagel et al., 2006) Has this altered understanding and approach to 'threats?
2	Mitigation	From around February 2020 onwards, what did your organisation do to prepare for lockdown?	How early did you start preparations for a potential lockdown? When were concrete measures first implemented at scale (e.g., WFH)? Were any measures implemented in the week before e.g., start a gradual move to working from home as cases were being confirmed?	Although it is being classed as a 'black swan', depending on how serious the threat was considered there was 'some' warning for organisations outside of China. Is the issue more that the type of required interventions (main one being social distancing) are different to normal? E.g., social distancing as a form of mitigation is not something that is applicable to many threats? Will this change going forward? Was social distancing or anything similar present in any pandemic plans?

3	Mitigation	Are there any steps that your organisation has taken previously that you think has helped with the response?	Are there any specific company strategies/ policies or recent changes to working systems that you think has helped in the response? Or any that have hindered? How did business continuity or contingency plans that were already in place work? Any social or 'employee resilience' related systems in place that has helped? Or previous changes to working practices? Resources that employees have access to that have helped? Did any preparations for Brexit help?	Again, operational and organisational! Thinking about employee resilience as a subsect of organisational resilience (Teng-Calleja et al., 2020). Any resources that their employees had access to that have helped? Physical- access to equipment (laptops, office chairs) as well as virtual- software programmes, wellbeing tools, social activities, technical training etc. Companies that moved towards a focus of hot desk working are now having to do the opposite (albeit hotdeskers might have laptops?- which will have helped with initial resources and equipment). Brexit planning and supply chain resilience was something that came out of the results from the questionnaire. Business continuity and contingency planning and effect it has- links to 'work as imagined vs. work as done'.
4	Mitigation	Prior to February 2020 had your organisation completed any vulnerability/ resilience assessment of the systems?	If yes were any/ what type of mitigating interventions were put in place and for what threats?	Were companies aware that certain parts of their system will not perform well under extreme stress? Has this transpired?

5	Adaptation	How has your organisation adapted your day to day working practices for lockdown?	Both organisational/ corporate level as well as day to day operations- difference between the two? What about differences between office / specifically non-office based staff e.g., those on water/wastewater treatment sites, mobile operatives, laboratory staff, construction work? Has this affected site visits, risk assessments, H+S protocol? Shared vehicle use?	Heavy focus on working from home? Do they foresee this being a long term move? When are the decision points for such? 1 week, 1 year or 1 amp? How about operations- has this changed to shift or staggered working patterns? Trained additional staff to extend response capabilities?
6	Adaptation	Leaving aside workplace and social issues has your organisation come across any unanticipated challenges during the lockdown period?	Have any of these challenges required further adaptation?	
7	Adaptation	What are the main actions or interventions that your organisation has implemented to adapt working	Have they been successful? Any teething issues?	Move to use of different or new technology out in the field? Are they using drones or?

		practices during lockdown?		
8	Coping	Has your organisation experienced any other large scale threats during this period that have required further action e.g., water resources and increased demand?	What was the largest incident you have faced? (specifics are not needed if that helps) How has the organisation coped with this during the current circumstances? How has this crisis affected the prioritisation of work and resources?	For example (sewer) flooding events, or has the lack of rain been causing any issues to supply? Any issues with more people being at home during the day. Any increases in sewer flooding? Water UK and water companies asking people to be more careful with their water consumption- hosepipe bans are forecast over the next few months. *This leads on to/ linked to next question*
9	Coping	Have you seen any noticeable changes in demand or use of the networks during this period? If so, how has the networks/ organisation in general coped with this?	Has household demand gone up? What figures are available /reported / discussed? Is the wastewater system seeing the same peaks as before with regards to diurnal flow? Has this had any impact on regional water management schemes, collaboration between companies? If focus has been water, then…."What can you tell me about wastewater too"? and vice versa.	Questionnaire and many reports state that diurnal flow has changed with IoW webinar stating that peak demand is now an hour later. Data on this exists from Germany- as well as press releases from UK companies e.g., Artesia, regarding highest ever demand. Reference to heavy Industry and sudden shut down and re-opening must have had some effect? How have the treatment works been able to respond to that? Biologically based water treatment works famously don't have a very fast response rate- can't quickly ramp up production- any lessons learnt or plans going forward with regards to this?

10	Coping	Do you see any links between resilience and the regional/ national water resources management plans? Or could this cause implications under extreme conditions?		Results from phase 1 (questionnaire) highlight the change in demand from classified 'commuter towns' and shift water usage across regions and water companies- e.g. from Thames to Essex and Suffolk. Are national/ regional plans helping combat or hinder such issues?
11	Coping	Do you have any specific examples of coping mechanisms that the organisation has used during this time that have been successful and effective? *How have you coped with local lockdowns?	Coping is defined as any action taken to reduce the effects of an impact.	Coping as a response to impacts and to minimise consequences-may need to explain further if not familiar with S&S.
12	Learning	What are the lessons that you have learned during this period?	Were these expected or unexpected lessons learned? Are there any cross organisational or industry wide lessons learned? Will you take these lessons learned forward to explore further? Is there, or will there be a structure for this?	Can any cross industry lessons learned be used to help innovation in other sectors? – this was something that came out of the questionnaire. Formal or informal structure in place for learnings?

13	Learning	Do you think that ultimately your organisation's working practices will return to pre lockdown status?	Organisational and operational.	Have changes to working practices highlighted better ways of working- thinking specifically with regards to operations- use of technology or change in working patterns?
14	Learning	How do you think this crisis will change your organisations working practices?	In the short term? <1 year In the long term? < Amp- 25 year strategic plan? Specifically, in relation to climate environment as this was a big theme coming out of the questionnaire.	Is there currently a plan being developed to facilitate this? What guidance is being used/ followed etc?
15	Learning	Do you think that this crisis will have any impacts on the wider water sector? Internationally- but also nationally, regulators and strategic planning, supply chain, contractors, consultants, etc.	If so, what impacts? Long term resilience strategy and funding of resilience based interventions? 5 year regulatory structure? Required planning or alternative working systems in place?	Do they see a change towards a more resilience based funding structure? Moving away from risk based- traditionally only funding things that have a high likelihood of happening? Again, anything with regards to climate and environment.
16	Learning	Is there anything that you think your organisation could have done to improve the response?	Is there anything the wider water sector could have done to improve? – Regulators- Defra etc.?	

17	Learning	What key challenges would you like to see more work / research completed on in the coming 1-2 years?		Challenges for operations and governance/ planning?
18	Learning	What are the positives that you are taking out of this period?		Validation that decisions to adopt increase in telemetry/ digitalisation, investment in network, was the right decision, confidence in organisations ability to respond etc.

Data collection and analysis

As outlined in Section 1.2.2, this work formed part of a wider Chartered Institution of Water and Environmental Management (CIWEM) facilitated project , with multiple researchers providing feedback to the researcher on the initial interview script draft, before the final script was agreed upon.

Purposeful sampling was used for semi-structured interviews in this research. Purposeful sampling is a technique centred on effective use of limited resources (Patton, 2002 cited by Palinkas *et al.*, 1968). Interview participants were identified by the CIWEM Policy Manager who formed part of the research group with invitations for participation in the interviews sent using personal connections. A letter from CIWEM CEO was included as an attachment to the email (Appendix A). An invitation to participate was sent to senior level individuals who were directly involved in the management of their organisations COVID-19 operational response. A total of fifteen initial invitations were sent out by CIWEM with efforts made to include a geographically diverse range of UK companies to account for differences in operating conditions. Once an individual agreed to participate in the research, they were sent a copy of the information and consent form which outlined further details of the research. Participants were required to sign and return the consent form before the scheduled interview date, a copy of which can be found in Appendix B. Verbal confirmation of consent to record the interview was also acquired by the researcher at the start of each interview.

Interviews took place between 21st July 2020 and 13th November 2020. The interviews were conducted via Microsoft Teams using the researchers University of Exeter account. Interviews were recorded using the record function on Teams as well as using a Dictaphone for back up purposes. Recordings were saved to the researcher's University One Drive account. Transcription of the interviews was carried out by the researcher using the qualitative data analysis software package NVivo (NVivo v.12, QSR International). In order to comply with the ethics procedure all names, references to specific organisations or places, and any further identifying

features were removed during the transcription process. Coding was also conducted in NVivo (Figure 3.3) by the researcher and one other member of the CIWEM research team. The coding process was carried out independently for each interview by the two researchers before being later discussed and found to be similar, thus providing validation of the results and analysis.

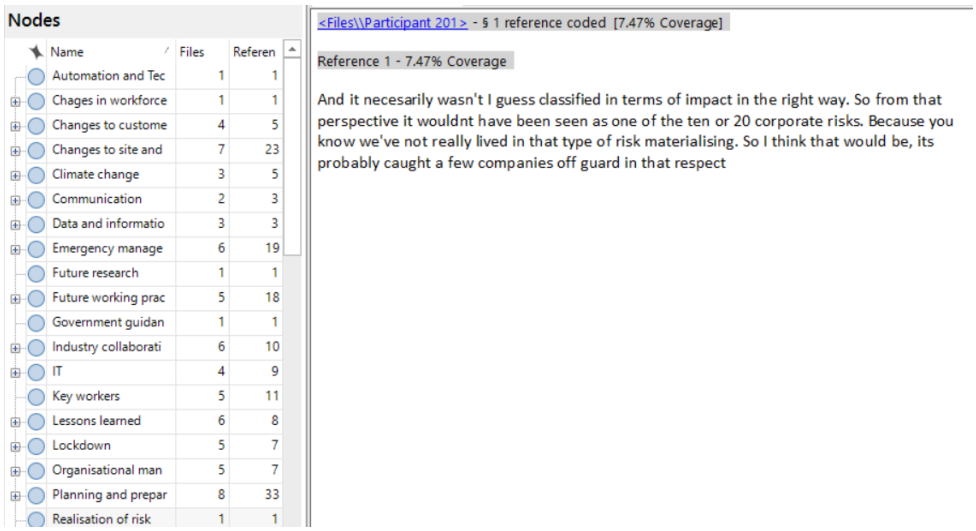


Figure 3.3 Example of codes developed from semi- structured interviews.

The second level of data analysis involved understanding the context of the information with regards to the Safe & SuRe framework. Emergent themes identified through coding were grouped into the four intervention categories of mitigation, adaptation, coping and learning.

This was plotted on the Safe & SuRe framework using the online collaboration tool Miro (Available at: https://miro.com) (Figure 3.4). Figure 3.4 is used to provide an overview of the tool and how it can be used in the analysis process, rather than to display results. Threats, system failure modes, impacts and consequences that were discussed and identified within the interviews were also plotted onto the framework, in order to provide the researchers with an initial visual example of the relationships between the data, and a demonstration of the Safe & SuRe framework itself. This was then shared with the other researchers involved in the CIWEM project for their feedback.

Ripple effect mapping (REM) was conducted for threats, system failure modes, impacts and consequences. REM is a qualitative data analysis method for conducting impact evaluation using a diagramming process that represents connections hierarchically (Koll*ock et al*., 2012). This process helps provide a visual representation of the implications of the threat, by highlighting both direct and indirect links. Both actualised and potential system failure modes, impacts and consequences that were discussed in the interviews are included in the REM as at the time of writing, the COVID-19 pandemic remains an ongoing incident. The second level of analysis was conducted collaboratively by three researchers and later validated by the wider research team. This was done using Miro and through regular meetings via Microsoft Teams. Although validation of the REM by interview participants would have been preferred, it was considered that this may have compromised the anonymity of interview participants, and their willingness to discuss incidents openly, and was therefore not pursued. An example of the Ripple Effect Map that was produced is provided in Chapter 5, Figure 5.1.

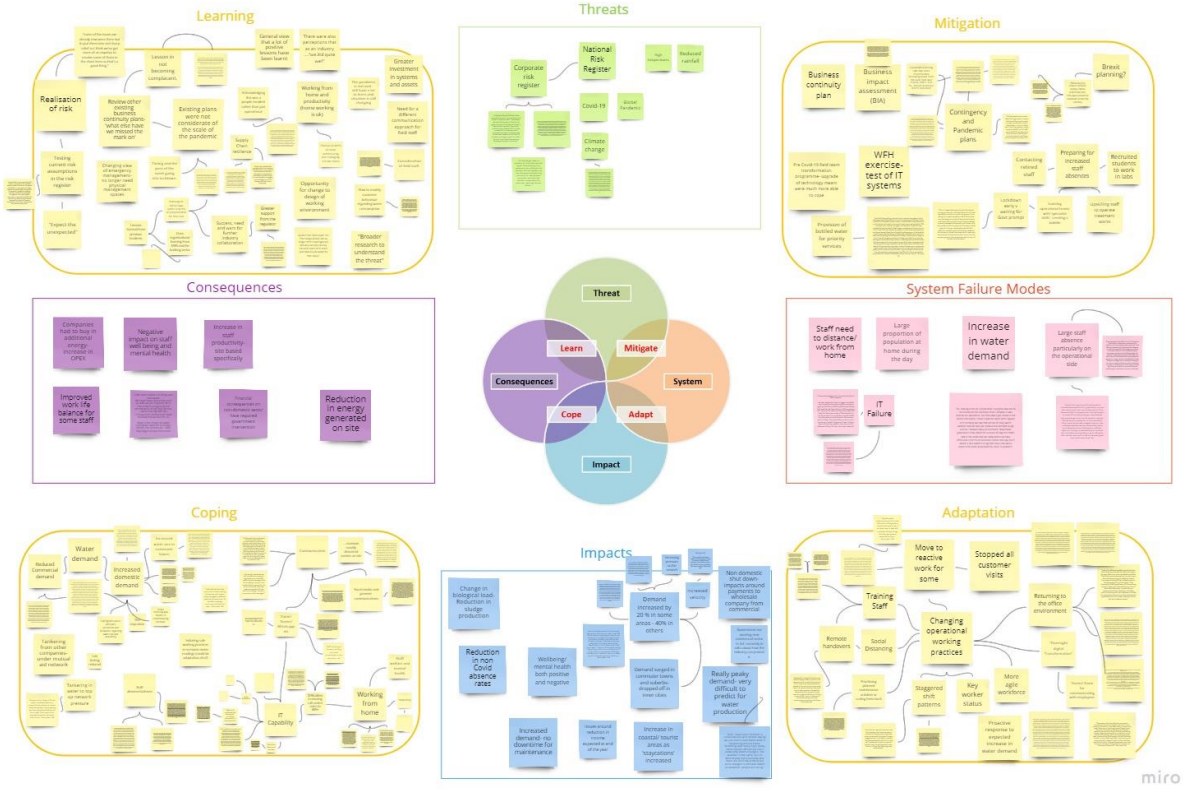


Figure 3.4 Plotting results onto Safe & SuRe framework

Ethical approval

Ethical approval was sought and received for this research from the College of Engineering Maths and Physical Sciences (CEMPS) Research Ethics Committee, University of Exeter on 18.05.20 (Ref: Emps000265) .

3.7.2 Research methods used to develop a resilience based application for use in the UK water sector (Objective 4)

Objective 4 applied a collaborative approach to the development of a resilience based online application through the use of participatory design.

A participatory design approach to software design ensures that users are involved throughout the design process, from identifying need to developing and testing the designed product. The democracy and empowerment of the users of the technology form the core principles of participatory design, with final design decisions based on consensual agreements between researchers and users (Baum *et al*., 2006).

Focus groups were employed as a qualitative research method to further include NW workforce members in the development of the resilience based online application during testing and validation. Two types of focus groups were employed in this research project as part of the development of a resilience based application, both in-person and online. A move for focus groups to be held solely online was required due to the outbreak of the COVID-19 pandemic in March 2020.

Figure 3.6 displays the development of the resilience based application and the research methods employed. The tool is based on the Safe & SuRe theoretical framework (Butler *et al*., 2016) and moves on from the Safe & SuRe user decision framework (Sweetapple *et al.*, 2019) which was developed in Microsoft Excel using Visual Basics Applications (VBA).

VBA is a computer programming language developed and owned by Microsoft which allows users to extend Office applications by adding new functionality and prompting users to interact with documents in ways specific to user requirements. VBA enables users to create macros to automate repetitive word and data functions, and to generate custom made, forms, graphs and reports. VBA does not exist as a separate stand-alone product and instead functions within MS Office applications.

As the Safe & SuRe user decision framework that was initially developed by Sweetapple *et al.*, (2019) was created using VBA in Microsoft Excel it was decided that the initial version of this tool would be created using the same software programme (Figure 3.5). This provided the researcher with the opportunity to become familiarised with the tool itself, its functionality and how it related to the Safe & SuRe theoretical framework. Benefits of the use of Microsoft Excel for the initial version of the tool include the prevalence of, and familiarity with Microsoft Office applications across the Northumbrian Water workforce, and the fact that users would not be required to download and install additional software that was not available to the wider workforce.

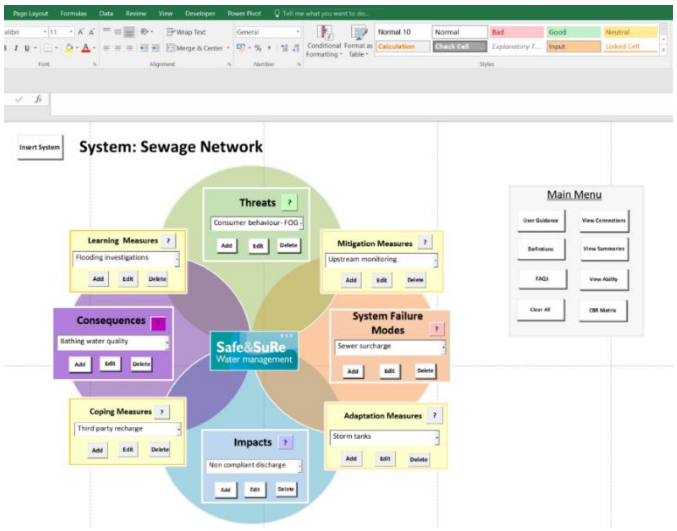


Figure 3.5 Resilience based application developed using Microsoft Excel VBA

Following feedback from the initial two in-person focus groups and the outbreak of the COVID-19 pandemic, it was agreed that the tool would be developed into an app

that individuals could access using handheld devices. Microsoft Power Apps was chosen as the programme that would be used to create the app.

Microsoft Power Apps is described as a ‘suite of apps, services, connectors and data platform that provides a rapid application development environment to build custom apps for your business needs’ (Microsoft, 2021). Power Apps allows users to build custom business apps that connect business data stored in either Microsoft Dataverse or in various online and on-premises data sources such as SharePoint, Microsoft 365, Dynamics 365 or SQL server.

Furthermore, apps built using Power Apps can run in browser or on mobile devices such as mobile phones or tablets. Microsoft themselves state that Power Apps “democratizes” the custom business app building experience by enabling users to build feature-rich, customer business apps without writing code (Microsoft, 2021), whilst still providing the opportunity for pro-developers to programmatically interact with data and metadata, apply business logic, create custom connectors, and integrate with external data.

The decision to further develop the resilience based application using Power Apps was based on the following reasons:

- Northumbrian Water recently extended the range of Microsoft applications available to all staff members to include Microsoft Power Apps.
- All operational staff members have access to either a smart phone and/or a tablet. The ability for users to easily access Power Apps via browser or mobile devices increases the availability of the tool across the organisation when compared with the previous tool based in Microsoft Excel using VBA, which could only be accessed via desktop.
- The functionality of the tool means that multiple users can view and edit data in the app at the same time. This is again in comparison to the tool based in Microsoft Excel using VBA, which is stored in one file, which although can be shared, can only be edited and viewed by one user at a time.

- The ability to store data in SharePoint allows for easier future integration with existing data sets and analysis processes used within Northumbrian Water.

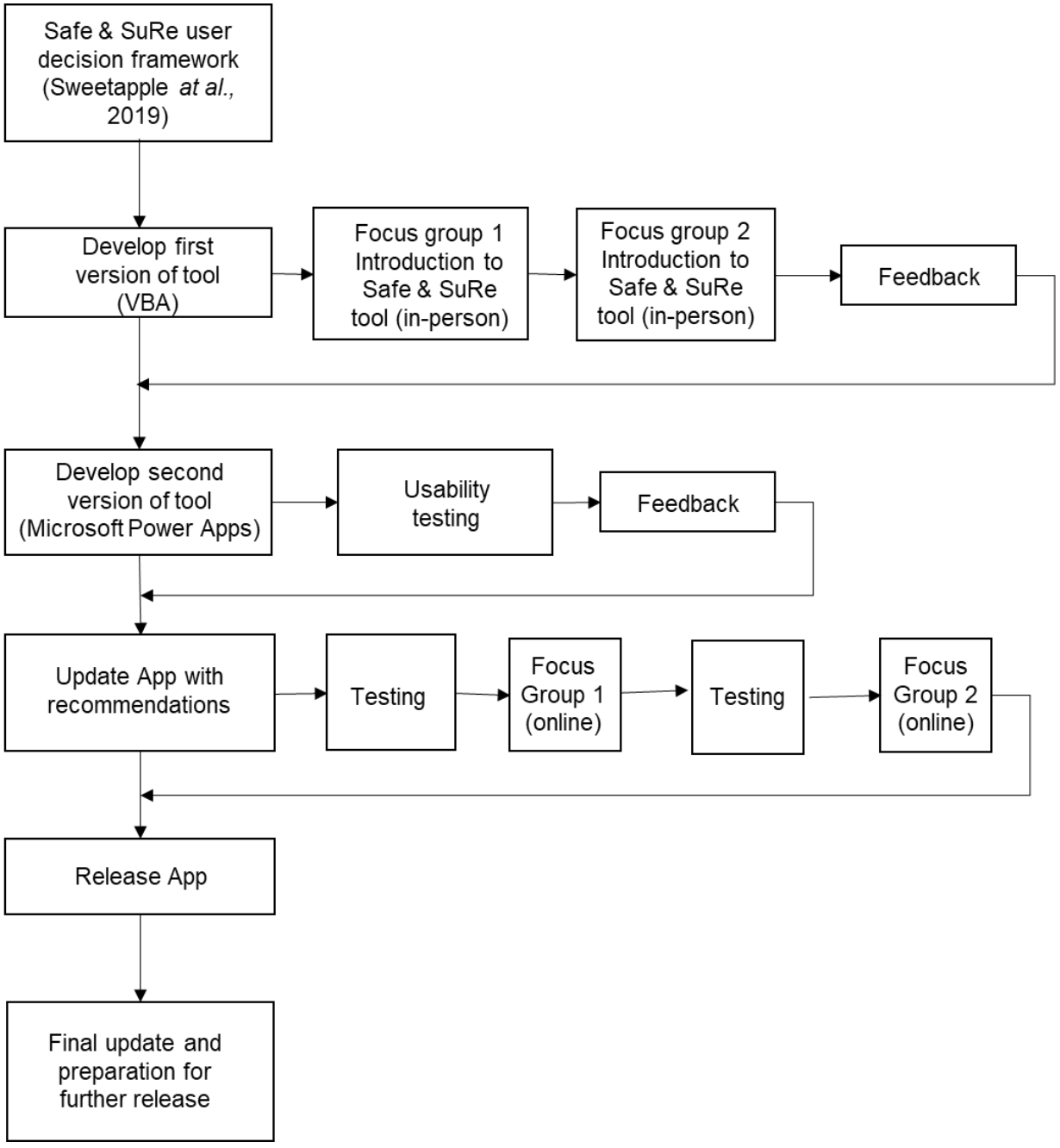


Figure 3.6 Development of resilience based online application

Focus group design - in person

Initial in person focus groups were designed to introduce the Safe & SuRe framework and the initial version of the resilience based online application to the NW workforce. The aim of the initial in person focus groups were to introduce and assess the suitability of the Safe & SuRe framework and user decision tool, and to introduce participants to a new way of approaching the topic of resilience.

Sessions were built around a number of group activities and were comprised of seven sections:

- Welcome and general introduction
- Introduction to Safe & SuRe framework and terminology
- Work through example of Safe & SuRe framework together as a group
- Introduce user decision tool
- Work through tool activity
- Discussion on basic suitability of tool
- Session feedback.

Focus group design- online

Online focus groups were designed as a series with the same group of eight participants attending each session. In total two online focus groups were held, as shown in Figure 3.6, with each moving on from the last. In advance of the first focus group, the researcher had a 15-30 minute introductory meeting with each participant, to introduce the project, the app and the structure of the focus groups themselves, via Microsoft Teams. An introduction to the app, how to download and install and user instructions were also sent to each participant in advance of the introductory meetings via email. All participants were then asked if they were happy to participate in the focus groups themselves and sent an invite to the online meeting.

Participants were asked to download, install and test the app in advance of the first online focus group. The first focus group in the series included a presentation to further introduce the topic of resilience, its relevance and relationship to the wider

water sector and more specifically NW. Discussion points in all focus groups were centred around three main themes:

1. Functionality of the app
2. Data obtained
3. Target users

Participants then went away to further test the app and provide feedback on where further improvements could be made. The following focus group built on the feedback and discussed the success or failure of updates that had been made to the app.

Data collection and analysis

The in-person focus groups took place on the 20.01.2020 and 18.02.2020 at Northumbrian Water site offices. The first in-person group included members of staff from the asset management directorate, with the second focus group consisting of staff based in the wastewater directorate. A third in person focus group with staff from the water directorate was planned for the 20.03.20, however this was cancelled due to the COVID-19 pandemic and was not rearranged. Online focus groups took place on 09.04.21 and 26.04.21.

In-person focus groups were held at NW site offices, with online focus groups hosted via the researcher's NW Microsoft Teams account. In person focus groups were audio recorded using a Dictaphone, with online groups recorded using the record function on Microsoft Teams and a Dictaphone for backup purposes. All recordings were stored on the researchers NW account in order to comply with the companies GDPR requirements. Purposeful sampling was also used for this part of the research process. Ken Black, the industrial sponsor of this project identified members of staff he thought would be the most willing to take part in the research. An internal email, including an outline of the focus group and wider project was sent to all participants to invite them to take part, using the researchers NW email account. Once participation had been agreed, an information and consent form was sent to all (Appendix C- in-person, Appendix D- online). A paper consent form was then signed

and handed to the researcher at the in-person focus groups, with an online version of the consent form sent back to the researcher via email in advance of the online focus groups.

Recordings were transcribed and analysed by the researcher using the NVivo software package. In order to comply with the ethics procedure all names, references to specific locations within the organisation, and any further identifying features were removed during the transcription process.

Ethical approval

Initial ethical approval was sought and received from the College of Engineering and Mathematics and Physical Sciences (CEMPS), University of Exeter on the 11.06.2019 Ref(Eemps000038 v2.1). Following the change from in person to online focus groups, and to account for the addition of semi-structured interviews to the project methodology, a secondary ethics application was submitted following advice from Dr Ewan Woodley. This approval was sought and received from the College of Life and Environmental Sciences (CLES)- Exeter Geography, University of Exeter on the 08.07.2020 Ref(eCLESGeo000702 v4.1).

3.7.3 Research methods used to develop policy and practice recommendations to enhance the successful operationalisation of resilience within the UK water sector (Objective 5)

Objective 5 focussed on the development of policy and practice recommendations based on findings from Objectives 1,2,3 and 4. A total of ten semi-structured interviews were carried out with NW staff members to provide further context to the current level of operationalisation of resilience within NW, and how a resilience based application could be introduced and adopted at the operational level.

Interview design

A semi-structured approach was adopted in order to facilitate more open discussion around the research topic, whilst also maintaining a clear structure across the eleven interviews.

An interview transcript (Table 3.4) was created to investigate the historical approach to resilience taken by NW and the wider sector, the approach taken to changes in regulation and policy, and changes required before resilience can be further operationalised.

Table 3.4 Semi-structured interview questions

Question Number	**Main questions**	**Follow up or clarifications**	**Comments**
1	How do you understand the term resilience with regards to Northumbrian water?	What does 'resilience' mean to you?	Work context rather than personal
2	In your opinion how does the organisation interpret and understand the term resilience?	Would you say there is a single clear understanding or definition of the term used across the organisation?	
3	Historically how would you say the organisation has approached the concept of resilience?		e.g., from a risk management perspective? Because they have to do it, only when regulator required more action around the topic?
4	How has the organisation approached related concepts? For example, risk management, or reliability, sustainability.	Adaptation, vulnerability etc. How does the organisation adapt to external changes and manage situations? Re phrase	How good are they at adapting? Are they very flexible?
5	Are there any significant changes to policy or regulation that you have	And what action has this resulted in from the company?	For example, additional requirements and expectations from

	noticed in relation to the concept of resilience?		regulators/ wider industry/ society?
6	How have any changes related to policy been viewed? Are such changes viewed as more opportunities or challenges?	What actions have then been taken and how has this filtered down to the operational level?	
7	In your opinion how would you say the concept of resilience is currently understood at the operational level?		
8	How would you say resilience is currently being operationalised within the business?	Is there centralised policy or plans? Is it up to individual directorates, teams, regions?	
9	Do you think anything needs to change within the business (at operational or corporate level) before resilience can be further operationalised?	What extra support is required- and from who? (external regulators in company?)	
10	Do you think it is possible to develop a 'culture of resilience' within the organisation?	What actions would need to be taken to help develop/ create such a 'culture of resilience' with the organisation? How could this be done/ what would need to be included?	Similar to how the health and safety culture has been developed over recent years- 60 second checks, use of Coruson (health and safety app) etc.
11	How do you think a resilience based app or some sort of application could be introduced to operational teams?	What other actions would need to be included or introduced e.g., training and educational materials provided?	
12	How can or will the app fit into everyday work practices for operational staff?		This is important for the concept of operationalisation. (operationalise

			meaning to put into effect or realise).

Data collection and analysis

Purposeful sampling was again used for the semi- structured interviews. Staff members who had worked for NW for a number of years and had both an understanding of water and/ or wastewater operations, and tactical and/ or strategic planning practices were identified by the project industrial supervisor Ken Black.

Potential participants were invited to participate in the research using the researchers NW email account. A brief outline of the project and what the interviews would entail was included in the invite. Once a date and time was agreed upon, an information form was sent to participants with the requirement to sign and return prior to the interview. The interviews took place from the 26.05.21 to 01.07.21. Interviews were conducted via the researchers NW Microsoft Teams account, recorded using the record function on Teams and on a Dictaphone for backup purposes.

Auto-generated transcripts were exported from Microsoft Teams into NVivo, where the researcher listened back to check the accuracy and edit accordingly. Coding of the data was then carried out in order to identify and categorise themes (Figure 3.7). All transcripts were reviewed multiple times to ensure they were adequately and accurately coded. Initial codes were collated into broader themes based on relationships and how themes would address the research questions.

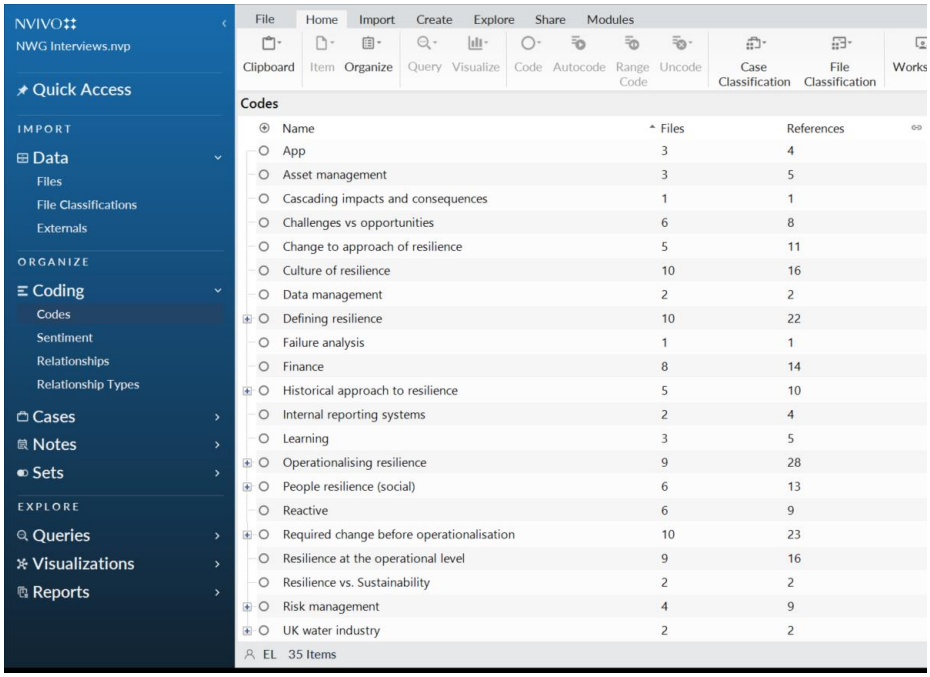


Figure 3.7 Coding of data in NVivo

Ethical approval

Ethical approval was sought and received from the College of Life and Environmental Sciences (CLES)- Exeter Geography, University of Exeter on the 08.07.2020 Ref(eCLESGeo000702 v4.1).

3.8 Ethical considerations

As previously identified, in order to meet requirements, set out by both the University of Exeter and Northumbrian Water Group, this work was subject to ethical approval due to the inclusion of human participants. The initial ethics application was submitted at the start of the research project to the College of Engineering, Mathematics and Physical Sciences where the researcher is based. However following discussions with the project supervisors, it was agreed that a following application should be submitted through the School of Geography within the College of Life and Environmental Sciences, as their ethics committee was considered to be more experienced with this form of application. An internal data governance

application was submitted to NW Governance and Data Protection Team and approval received on 02.05.2019.

The ethical issues within the application were not considered significant and therefore mitigations were agreed upon with supervisors and members of NW data protection team in advance of the ethics and internal data governance application submission. Each of the identified issues and agreed upon mitigation measures are outlined below.

1. Consent- All participants were provided with an information and consent form which provided an overview of the project and what each of the specific research activities entailed. The consent form allowed participants to indicate their consent after all of the information about the study had been provided. Participants were advised that participation was voluntary, that they could withdraw from the research at any time and that they would not personally profit from participation in anyway.

2. Confidentiality- The consent forms outlined that all personal information and responses would be treated with confidentiality. This would be achieved by storing personal information separately to the associated data and maintain anonymity of all participants in any associated reports or publications. Any names or identifying factors/information were removed from transcripts.

3. Data storage- Any documents containing personal data of NW employees (e.g., signed ethics forms) was stored on the researchers NW OneDrive account. All other data was stored on the researchers University of Exeter account.

3.9 Chapter summary

This chapter has provided a detailed outline of the case study, research approach and methodologies, and data analysis techniques employed in this research.

Additionally, the chapter discusses ethical considerations required to ensure that the research meets the required standards.

Both qualitative and quantitative methods have been utilised in order to provide in-depth data collection and analysis in order to aid the development of a strategic framework for the operationalisation of resilience in the UK water sector.

Chapter 4: Resilience understanding- Pilot study

4.1 Introduction

The literature review in Chapter 2 suggested a lack of clear understanding, unity and clarity of the term resilience across the UK water sector. It was therefore decided that an indication of the baseline understanding of the term ‘resilience’ within and across the NW workforce, would aid further planned research.

A questionnaire survey was carried out in advance of the main data collection focus groups and interviews, with the aim of gaining a base understanding of the concept of resilience within the NW workforce. This chapters aims to contribute to Objective 1 and the following research question:

i. How is resilience currently understood in the UK water sector?

The survey was structured around members of the workforce, their understanding of resilience and view on the relevance of resilience to the UK water sector, and more specifically their role within NW. A questionnaire script was therefore designed and can be seen in Table 4.1. The final survey consisted of 13 main questions, and 26 total questions when inclusive of sub questions, with three modalities: multiple choice (6), open response (7) and likert scale (13). The questionnaire sought to find out the current understanding of the term resilience within the NW workforce; how individuals define the term resilience in general and with regards to the organisation; how relevant they consider the term ‘resilience’ to be to the UK water sector and the work that NW does; how the workforce rates NW against the seven themes of highly resilient organisations identified by Wreathall, (2006); how they currently view the resilience status of the organisation and wider sector; and finally gain insight into resilience communication within the organisation. The framework by Wreathall was chosen for use as an existing organisational resilience framework that had previously been applied in multiple sectors.

The questionnaire was created using the online survey platform Netigate, which is Northumbrian Water's chosen internal survey platform. Ethical approval was obtained from both the University of Exeter and NW as outlined in Chapter 3. The survey was distributed to the workforce via the organisation's intranet home page 'Cascade' alongside an accompanying article (Figure 4.1), and a post on the NW Yammer page. All members of staff have access to both Cascade and Yammer, therefore it was agreed with the internal communications team that this would be the most effective way of distributing the questionnaire within the organisation. Following emails were later sent out to all Level 2 managers across the business asking them to complete the survey and to continue to disseminate within their teams. In the final week that the survey was live, one last follow up email was sent to teams within directorates that had seen low response rates.

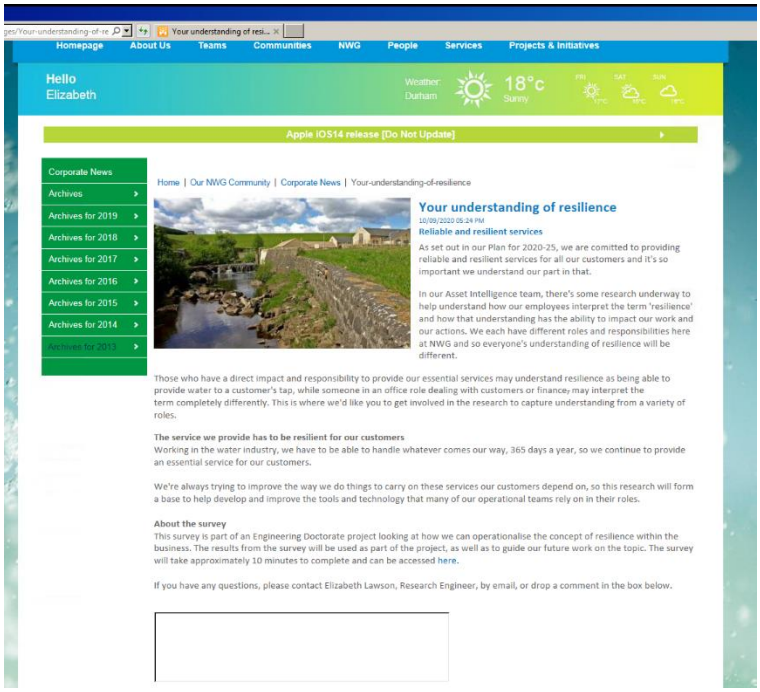


Figure 4.1 Article posted on Cascade asking staff to complete questionnaire

The organisation's workforce is made up of approximately 3,000 people and includes a wide range of roles from treatment site operators and customer service agents, to laboratory analysts and asset planners. The questions were tested in advance by individuals from both the University of Exeter and NW in order to ensure clarity and suitability. The first question displayed when respondents opened the survey

included information on the nature of the survey and how the data would be used (Figure 4.2). Users were then asked whether they agreed to take part in the survey following the provision of this information. If a participant selected 'I do not agree', their responses would still be collected and stored by Netigate, however their data would be deleted prior to data analysis.

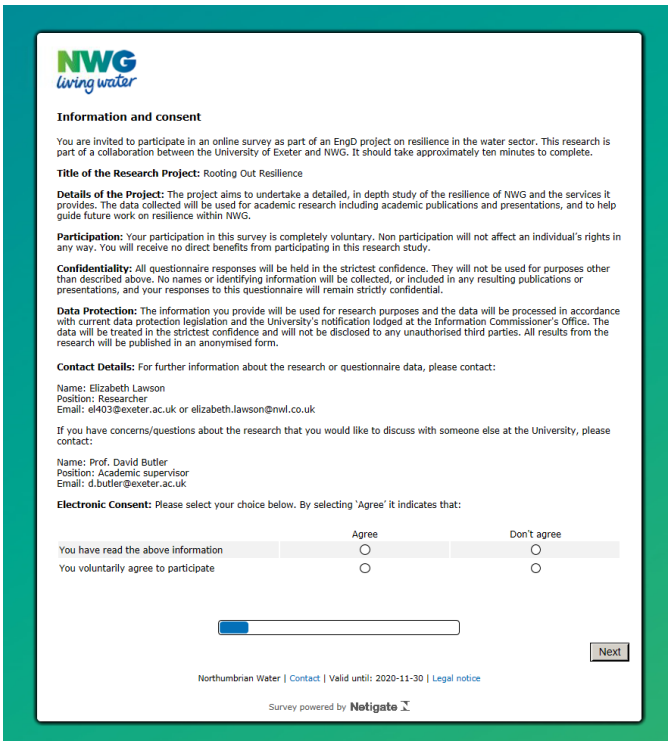


Figure 4.2 Information and consent form on questionnaire

Members of staff from the employee communications team 'owned' the survey in Netigate, whereby the researcher submitted the questions and format request to the team who then controlled the questionnaire via the central company Netigate account. Results from the questionnaire survey were downloaded into an Excel spreadsheet and sent to the researcher via email.

Table 4.1 Question phrasing and modality in the understanding resilience survey

	Question	**Response type**
	Section one: About you	

	1	Please select your directorate	Multiple Choice
	2	Please select your location	Multiple Choice
	3	What would best describe you?	Multiple Choice
	4	Please select which best describes your usual work status?	Multiple Choice
	Section two: Defining resilience		
Part one	5	Please explain what the term ‘resilience’ means to you	Open response
	6	Please explain how you understand the term ‘resilience’ with regards to NWG and the service it provides?	Open response
	Section three: Relevance of resilience		
	7	If resilience, with regards to an organisation was to be defined as “the ability to cope with, and recover from disruption and anticipate trends in variability in order to maintain services for now and in the future”	
	a	How relevant do you think organisational resilience is for the water sector in general?	Likert scale
	b	How relevant do you think organisational resilience is to the work that NWG does?	Likert scale
	Section four: Resilient organisations		
Part two	8	Please rate the following statements from strongly agree to strongly disagree using the scale provided.	
	a	NWG management recognises workforce and operational performance concerns and tries to address them.	Likert scale
	b	NWG supports the reporting of issues up through the organisation and deals appropriately with those issues.	Likert scale
	c	NWG has a true learning culture and looks to continuously respond rather than deny.	Likert scale

	d	NWG has a thorough data gathering process for both people and asset performance	Likert scale
	e	NWG actively anticipates problems and prepares for them.	Likert scale
	f	NWG has the ability to fix complex problems.	Likert scale
	g	People at the working level are supported and empowered to make important decisions without waiting for management instruction.	Likert scale
	h	NWG is aware of the balance between risk and cost and knows how close it is to ‘the edge’ in terms of risk.	Likert scale
	Section five: Resilient sector		
Part three	9a	I consider NWG to be resilient.	Likert scale
	b	Please explain your answer	Open response
	10a	I consider the UK water sector to be resilient.	Likert scale
	b	Please explain your answer	Open response
	Section six: Resilience communication		
	11a	In your opinion, does NWG provide enough information to its workforce on organisational resilience?	Multiple choice
	b	Please explain your answer	Open response
	12a	In your opinion, does NWG provide enough information to its workforce on organisational resilience and how it applies to your role?	Multiple choice
	b	Please explain your answer	Open response
	Section seven: Further comments		
	13	Do you have any further comments or thoughts on the topic of organisational resilience with regards to NWG and the wider water sector?	Open response

The survey was open from 09.09.20 and closed on 02.11.20. The response rate (3.2% of people employed by NW) reflects the large number of respondents polled, the broad specialisms within the workforce and the difficulties surrounding obtaining survey responses. The difference in nature of job roles that make up a large proportion of the NW workforce, is also reflected in the response rate.
For example, approximately 50% of the workforce are site/field based, or remote workers and therefore do not have constant access to a computer and are unlikely to regularly check the organisations intranet page (internal communication Black, 2020). This is reflected in the responses to question 4 *'Please select which best describes your usual work status'* with only 7.6 % of responses coming from site-based staff in comparison to 56.1% coming from office-based staff (Figure 4.3).

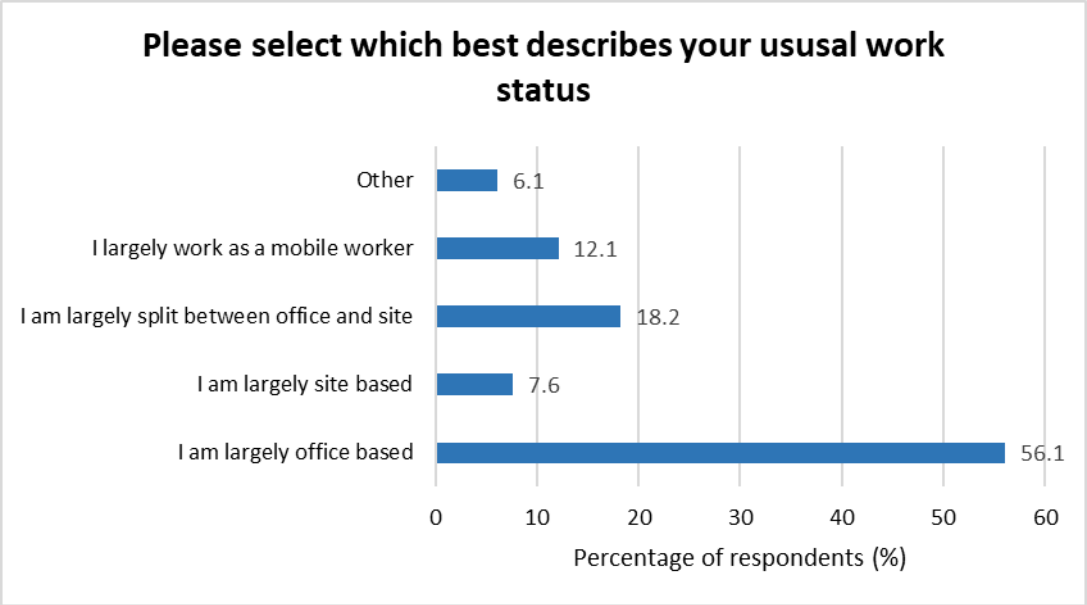


Figure 4.3 Q4 Please select which best describes your usual work status.

4.2 Survey format and data analysis

The survey was split into seven sections, as shown in Table 4.1. Open responses were analysed using a qualitative data analysis software package (Nvivo v.12, QSR International) and were coded into themes (Figure 4.4). Nvivo is a qualitative data analysis computer software package produced by QSR International, which helps qualitative researchers to organise, analyse and find insights in unstructured or

qualitative data such as interviews, open-ended survey responses and social media content.

The remaining questions were multiple choice or Likert scale and allowed participants to express how much they agreed or disagreed with a statement. Quantitative data analysis was done using the IBM SPSS package. A total of 96 responses to the questionnaire were received and logged by the Netigate platform. However only 66 of those responses had reached the end of the survey, the other 30 had started the survey but not completed it. Therefore, it was decided that analysis would only be done on the 66 responses that had been completed. The average time to complete the survey was reported by Netigate to be 15 minutes and 54 seconds.

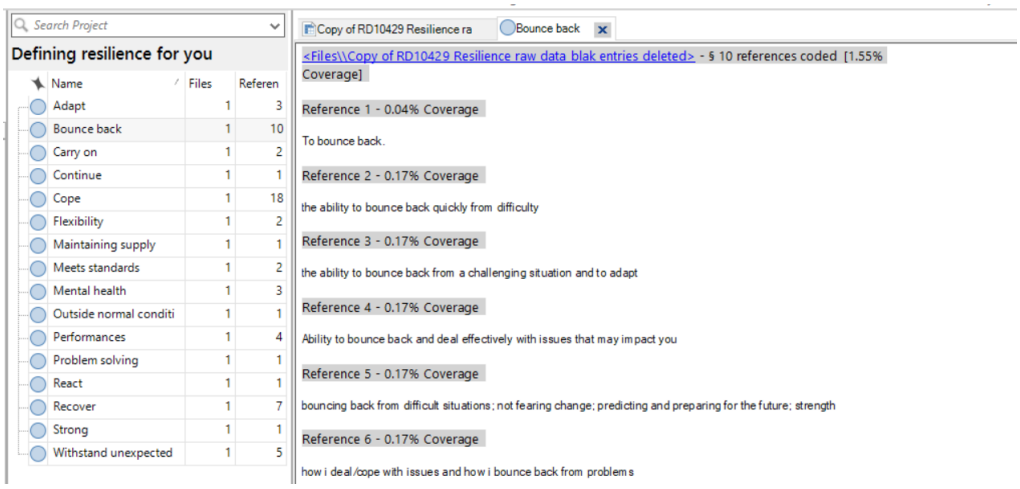


Figure 4.4 Example of codes from pilot study analysis

4.3 Results

The results from the questionnaire are presented in three parts, aligning with the order of the questions. Part one focuses on the understanding and definition of resilience along with the relevance of resilience to the water sector in general. Part two looks at NW as a resilient organisation and the resilience of the wider water sector. Part three then looks at communication around the topic of resilience.

4.3.1 Participant profile

Of the three operating areas that make up NW, 78.8% of participants were based in the north, with 20.6% in Essex, 7.3% in Suffolk and 3% who did not answer (Figure 4.5). 57.6% of participants viewed themselves as an employee with no managerial responsibilities, 34.8% as managers and 7.6% as team leaders. The high level of respondents in managerial positions would indicate that there is a good level of organisational awareness and understanding amongst participants.

56.1% of responses were from largely office-based staff, 18.2% of participants were split between office and site, 12.1% from mobile workers, 7.6% site based and 6.1% who selected 'other'. Those who selected 'other' provided further information in the accompanying text box and were mainly laboratory or home-based workers. This does not represent the split of the NW workforce, with workforce split reported as 50: 50 between those who typically work in an office environment and those who are site and field based.

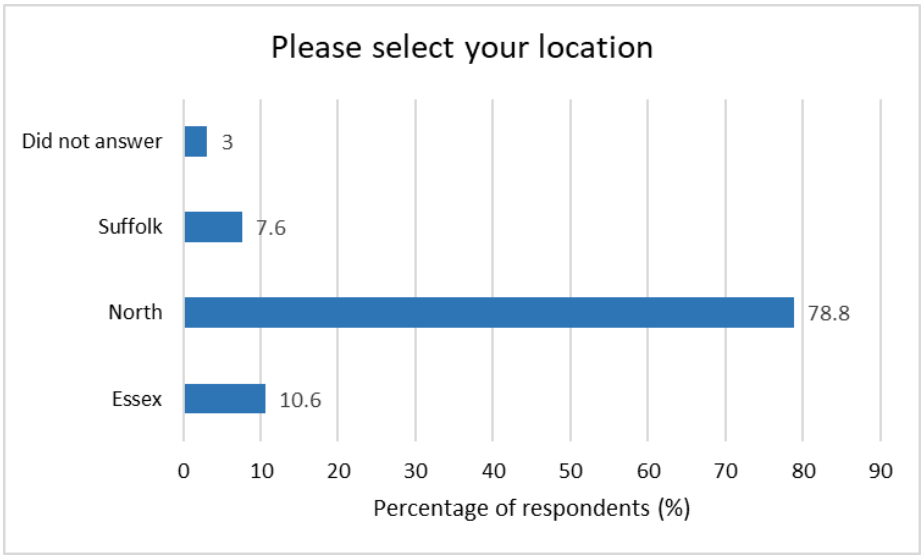


Figure 4.5 Location of questionnaire respondents

4.3.2 Resilience definition and understanding

Part one of the questionnaire was dedicated to providing respondents with the opportunity to describe how they understand the term ‘resilience’. Question 5 focused on what the term ‘resilience’ means to the respondent, with question 6 asking respondents to ‘explain how you understand the term ‘resilience’ with regards to NW and the service it provides’. Both question 5 and 6 were open response providing respondents with the opportunity to write as much or little as possible in response to the question.

Responses to both questions were varied and covered a range of understandings and approaches to the topic of resilience (Table 4.2). The most popular themes relating to Q5 was that of ‘bounce back’ and ‘coping’. This is in comparison to the answers for Q6 where ‘bounce back’ was only referred to by one participant. In general, responses with regards to resilience and the individual (Q5) were centred on the ability to recover and ‘withstand’ where Q6 more heavily focussed on assets and the customer.

Responses to both Q5 and Q6 emphasise a clear lack of unified understanding of the term ‘resilience’ within the survey participants, especially with regards to NW and the services it provides.

Table 4.2 Open ended responses to Q5 and Q6

Please explain what the term ‘resilience’ means to you.	**Please explain how you understand the term ‘resilience’ with regards to NWG and the services it provides.**
“Accepting that at times, things in the world of work and my job will be difficult at times but having the ability to withstand those difficulties, adapt where necessary to still perform to the best of my abilities”	“I’m not 100 per cent sure but I suppose it would be how they would cope in ever-changing circumstances”
“Personal view is Resilience is the ability to cope with adverse change and bounce back from critical threatening events”	“Having the capability to provide the quality finished products to the user of the material with no compromise to excellence”
“The term resilience to me is personal. It means how I am able to bounce back	“We need to be flexible and consider customer demands/requirements to ensure we provide the services they

from life's issues or situations which may be perceived as negative."	need. We also need to balance business requirements with service delivery to be cost effective."
" To me it mainly means environmental resilience - safeguarding our habitats and species as best we can for now and the future. For NWG this should relate to investment in carbon efficiency, reducing our impact and making a positive contribution to securing resilience in the environment so it can withstand change."	"Resilience within NWG means having the capacity within its asset base and organisational structure and procedures to deal with infrequent or emergency operating scenarios such as high demand for potable water, burst water or pumping mains or the loss of treatment capacity at water or sewage treatment works."
"Being able to cope under pressure and bounce back after a knock back."	"Ensuring our systems and networks are robust enough so that we can cope with all incidents, events and issues with no noticeable effect on the service we provide to our customers."
"Knowing how to recover from anything I may face. For example, if I am stressed, I would know how to de-stress."	"Ability to maintain unbroken service"

4.3.3 Resilient organisations

Question number eight was developed using the seven themes of highly resilient organisations as outlined by Wreathall, (2008). The seven themes and the associated questions are outlined In Table 4.3.

Table 4.3 Seven themes of highly resilient organisations and associated questions. Adapted from (Wreathall, 2008)

Resilient Organisation themes	**Definition**	**Adapted question for use in survey (likert scale)**
Top-level commitment	Top management recognizes the human performance concerns and tries to address them, infusing the organization with a sense of significance of human performance, providing continuous and extensive follow-through to actions related to	NWG management recognises workforce and operational performance concerns and tries to address them.

	human performance, and is seen to value human performance, and is seen to value human performance, both in word and deed.	
Just culture	Supports the reporting of issues up through the organisation, yet not toleration culpable behaviours. Without a just culture, the willingness of the workers to report problems will be much diminished, thereby limiting the ability of the organization to learn about weaknesses in its current defences.	NWG supports the reporting of issues up through the organisation and deals appropriately with those issues.
Learning culture	A shorthand version of this theme is 'How much does the organization respond to events with denial versus repair or true reform?'	NWG has a true learning culture and looks to continuously respond rather than deny.
Awareness	Data gathering that provides management with insights about what is going on regarding the quality of human performance at the plant, the extent to which it is a problem, and the current state of defences.	NWG has a thorough data gathering process for both people and asset performance
Preparedness	'Being ahead' of the problem in human performance. The organisation actively anticipates problems and prepares for them.	NWG actively anticipates problems and prepares for them.
Flexibility	It is the ability of an organisation to adapt to new or complex problems in a way that maximises its ability to solve the problem without disrupting overall functionality. It requires that people at the working level (particularly first-level supervisors) are able to make important decisions without having to wait unnecessarily for management instructions.	NWG has the ability to fix complex problems. People at the working level are supported and empowered to make important decisions without waiting for management instruction.
Opacity	The organisation is aware of the boundaries and knows how close it is to 'the edge' in terms of degraded defences and barriers.	NWG is aware of the balance between risk and cost and knows how close it is to 'the edge' in terms of risk.

Participants were asked to rank questions relating to the seven themes from strongly agree, to strongly disagree with results shown in Figure 4.6. The results show that 74.2% of participants either agree or strongly agree that NW has the ability to fix complex problems. This is in comparison to the 37.8% that either agree or strongly agree that NW actively anticipates problems and prepares for them, highlighting a view from participants that NW's strengths lie in response rather than preparedness.

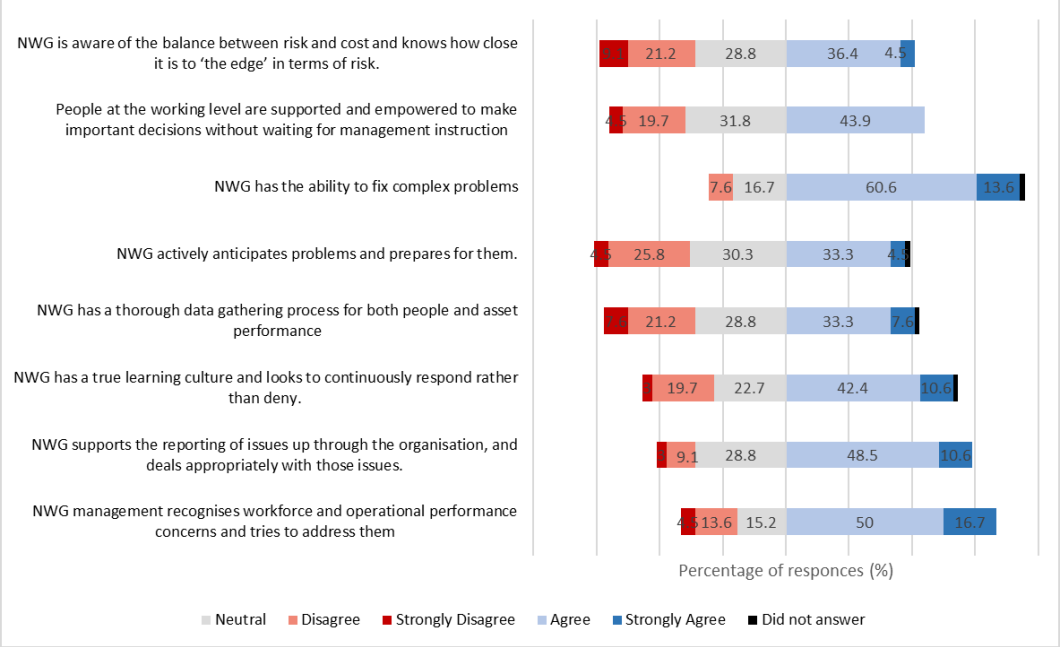


Figure 4.6 Q8: Resilient Organisations

When broken down by directorate Figure 4.7 highlights that the highest percentage of respondents who either disagree or strongly disagree with the statement 'NW actively anticipates problems and prepares for them', are from water, regulation and asset management. This would suggest that those who are more involved with the day-to-day operation and maintenance of the physical assets are more likely to disagree with the statement.

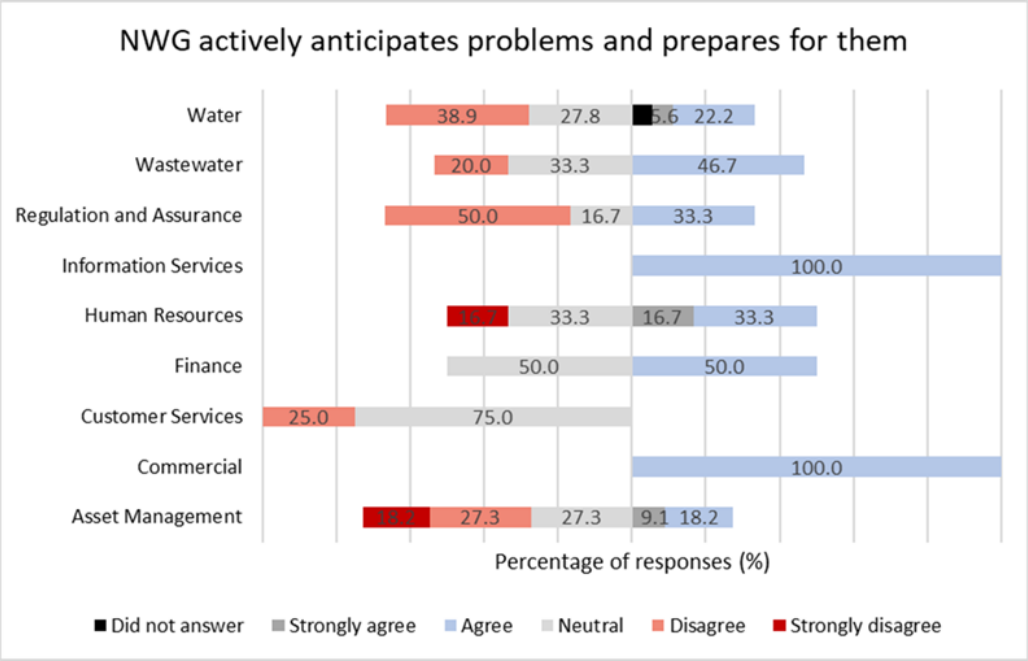


Figure 4.7 NW actively anticipates problems and prepares for them

Figure 4.8 shows the responses to the statement ‘NW has the ability to fix complex problems’ by directorate. It highlights that a large proportion of respondents across the directorates either agree or strongly agree with the statement.

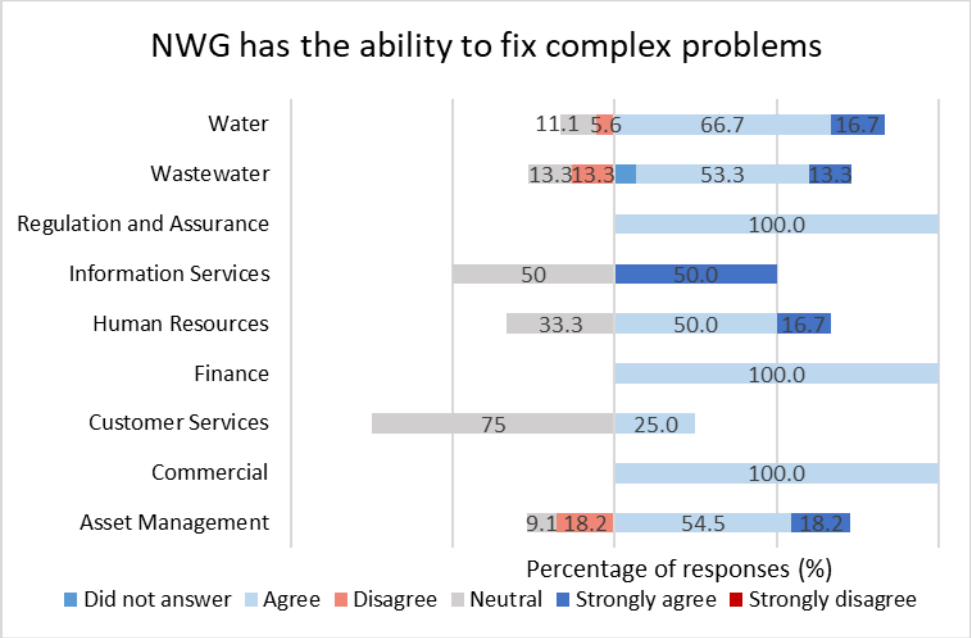


Figure 4.8 Q8f: NW has the ability to fix complex problems by directorate

Participants views on the resilience status of both NW and the wider sector are shown in Figure 4.9. This shows 53% of respondents who either agree or strongly agree with the statement 'I consider NW to be resilient' in comparison with just 39.4% of participants that agree or disagree with the statement 'I consider the UK water sector to be resilient'. Although the results highlight a higher perceived level of resilience for NW than the wider sector, 25.7% of participants still either disagree or strongly disagree that NW is resilient. Questions 11 and 12 both had follow-up questions which provided an option for respondents to explain their answer.

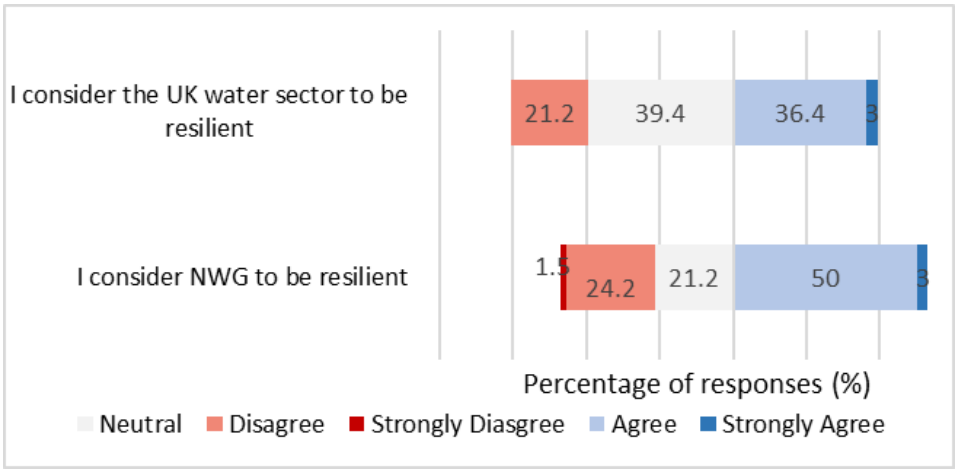


Figure 4.9 Resilience of NW and UK water sector

4.3.4 Resilience communication

The final section of the survey was based around resilience communication within the organisation. Responses to questions 11 and 12 are shown in Figure 4.10.

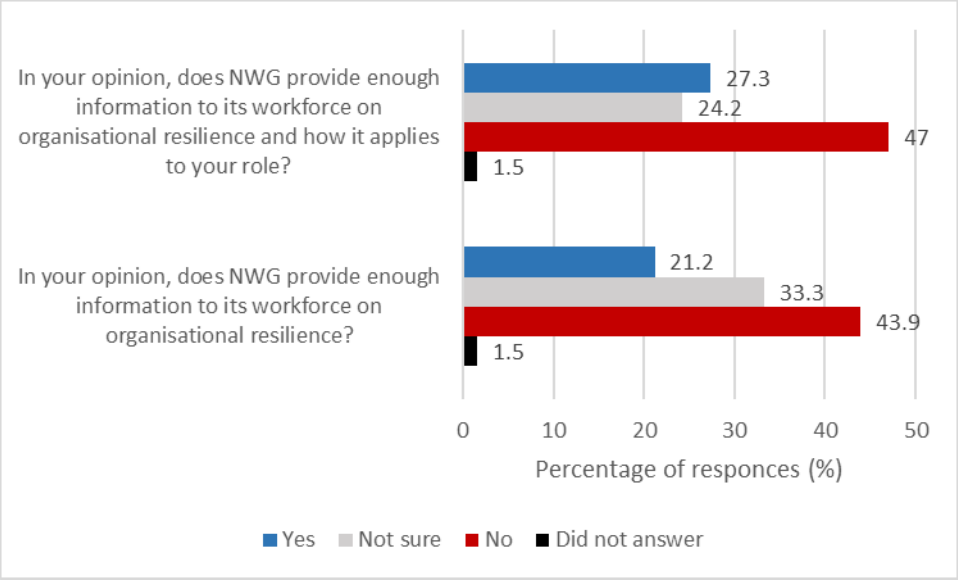


Figure 4.10 Resilience communication in NW

43.9% of participants hold the view that NW does not provide enough information to its workforce on organisational resilience. This is in comparison to the 21.2% of participants who think NW does provide enough information to its workforce on organisational resilience. 33.3% of respondents stated, ‘not sure’ and 1.5% did not answer. 47% of participants respondents answered ‘no’ to the question ‘In your opinion, does NW provide enough information to its workforce on organisational resilience?’, with 27.3% answering ‘yes’, 24.2% said ‘not sure’, and 1.5% did not answer. This suggests that employees would welcome further centrally distributed information on organisational resilience and how it applies to individual roles.

4.4 Discussion

Results from the pilot questionnaire were split into three themes: resilience understanding and definition, resilient organisations, and resilience communication.

The research has suggested that there is a lack of collective understanding of the term resilience within the NW workforce. Many of the responses to Q5 and Q6 focussed on the ability to 'bounce back' and to 'cope', with responses to Q6 heavily focussed on assets and physical engineered systems as well as the customer. The tendency of water sector employees to relate the concept of resilience with the engineering centred definition of the term resilience, mirrors the historical approach to the resilience concept that the water sector in the UK has taken (Lawson *et al.*, 2020). Specifically with regards to a focus on the reliability, recovery and bounce-back ability of engineered assets (Rodina, 2019). Research conducted by Sakai and Dessai, (2015) in which insights were gained from the UK water sector regarding resilience framing and adaptation to climate change, found the dominant framing of resilience to be that of the engineering resilience framework. Results from this pilot study found that at the time of writing this was still the case, with the engineering centred approach to the concept of resilience still the most dominant approach found within the NW workforce.

Results from the survey also suggested that the NW workforce perceive the organisations strengths to lie in response, rather than preparation. With respondents from asset intensive directorates including water, wastewater and asset management more likely to agree with this sentiment. Possible reasoning for such a trend could include that those tasked with the day to day operation of assets, are much more aware of the ability of the assets to meet required levels of performance under varying conditions. However, more data is required before this can be certain. The recent focus of the UK water sector on short-term planning and investment rather than long-term is also reflected in the above results. Sakai and Dessai, (2015) also found resilience to be helping short-term but not long-term adaptation in the water sector.

Results from the pilot study emphasised a lack of clear understanding of the term resilience within the Northumbrian Water workforce. A desire for the organisation to provide further information on how the term is defined and how it relates to individual

roles was also shown. Discussions around a lack of singular and clear definition of the term resilience for the water sector have been continuing for some time now, with initial suggestions for Ofwat to adopt and enforce a single definition made by the resilience Task and Finish Group in 2015 (Ofwat, 2015). Such results indicate that little progress has been made in this area since.

The low level of participation in the survey means results could not provide a representative sample and were instead only indicative of the workforce their level of understanding, thoughts and opinions on the topic of resilience. The results gained from the pilot study questionnaire influenced the development of the interview transcript that is discussed in Chapter 7. The use of semi-structured interviews (Chapter 7) provided the opportunity to discuss in more detail the themes that had arisen from this pilot study.

4.5 Chapter summary

This chapter has presented results from a questionnaire survey that was conducted with the aim of gaining a base understanding of the concept of resilience within the NW workforce. In answering the research questions that were posed at the beginning of the chapter in Section 4.1, it was identified that:

- Results showed a range of understandings of the term resilience within the NW workforce.
- Members of the workforce considered NW to have a higher level of resilience compared with the wider UK water sector.
- The analysis suggests the workforce perceive the company's strengths lie in response rather than preparation.
- Results also highlight an appetite for increasing central communication from the organisation around the topic of resilience and more specifically how it relates to individual roles.

Chapter 5: Application of a resilience framework for analysis: COVID-19 and the UK water sector

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5.1 Introduction

As outlined in both Chapter 1 and Chapter 2, multiple resilience based theoretical frameworks have been developed and defined at a strategic level. However, questions remain around how such frameworks can be used to provide decision makers with guidance on the operationalisation of resilience, as well as the current operating state of their systems.

This chapter aims to explore how a resilience based theoretical framework can be used to assess organisational resilience, through the use of the Safe & SuRe resilience framework. A case study approach will be applied with the framework being used to analyse organisational and operational response to the COVID-19 pandemic in the UK water sector. As such this chapter addresses Objective 3 which posits the following research questions:

i. How can the Safe & SuRe framework be used to design a research methodology?
ii. How can the Safe & SuRe framework be used to assess system performance?
iii. How did the UK water sector respond to the COVID-19 pandemic?
iv. How has the COVID-19 pandemic impacted the resilience of the UK water sector?

The Safe & SuRe framework was used to design a set of semi- structured interview questions with questions based on the four stages of intervention identified in the

Safe & SuRe framework (mitigation, adaptation, coping and learning). The opinions, perceptions, and experiences of UK water industry executives, involved in their organisations response to the COVID- 19 pandemic, are then analysed using the framework to assess organisational and operational response.

The remainder of the chapter is structured as follows; Section 5.2 introduces and provides context to the COVID-19 pandemic and this research, Section 5.3 outlines how the framework was applied along with a profile of those interviewed and the creation of the Ripple Effect Map (REM). Section 5.4 goes on to discuss the threats, system failure modes, impacts and consequences discussed by participants and outlined in the REM, with section 5.5 discussing operational and organisational response. Finally, Section 5.6 provides a summary of the key themes and conclusions.

5.2 Case study: COVID-19 pandemic and the UK water sector

At the time of writing, the COVID-19 pandemic continues to alter the way with both live and work, with consequences felt across all areas of society. During this time, the need to ensure safe and reliable water and wastewater services has become more critical than ever due to the pivotal role that hygiene plays in mitigating the spread of disease (Poch *et al.*, 2020).

In the UK, national restrictions were initially imposed on Monday 23rd March 2020 with the first round of easing of restrictions occurring on Saturday 4th July 2020. Since then, the UK has been through a further two nationwide lockdowns with a number of regional variations of restrictions in place in the periods between nationwide restrictions. During periods of ‘lockdown’, residents were only able to leave their homes to travel to work where necessary, to shop for essential items, to exercise once a day, or to access medical care (Iacobucci, 2020). The UK water sector was identified as ‘key workers’ meaning staff were able to continue their roles at their place of work providing all relevant safety measures were met. As highlighted by Farquharson *et al*., (2020) the resilience of the UK economy and wider society

largely depended on the ability of key workers and organisations to respond to, and adapt in order to maintain performance of key services (Cot*terill et al*., 2020).

Within the initial stages of the pandemic efforts to track the level of community infection of SARS-CoV-2 through the analysis of wastewater (Mao *et al.*, 2020) and a focus on the efficacy of the drinking water processes (Maal-Bared *et al*., 2020) were promptly investigated by researchers around the world. However, the impact of the pandemic on water systems goes beyond engineering and treatment processes with social, economic and environmental consequences such as increases in demand, reductions in revenue, and an increase in public engagement with local water environments already occurring.

For many organisations the COVID-19 pandemic has significantly tested organisational resilience through their ability to anticipate the impact and consequences within a complex socio-technical environment. It was therefore agreed that the initial response to the COVID-19 pandemic would be analysed using the Safe & SuRe framework. Results from the analysis would provide organisations with examples of successful intervention and areas in which more additional action could be taken in order to maintain system performance and aid overall system resilience.

5.3 Applying the framework

As outlined in Chapter 3, a semi- structured interview script was developed around the four interventions identified in the Safe & SuRe framework (mitigation, adaptation, coping, learning) (Butler *et al.*, 2016). The full list of questions can be found in Table 3.3. The questions explored any pandemic related preparations that organisations had carried out, methods of adaptation during the pandemic, other large scale threats during the period that had required further adaptation, unanticipated challenges, the effectiveness of coping mechanisms, overall reflections on measures implemented, and lessons learnt so far.

The analysis consisted of two stages. First thematic analysis was conducted on the transcribed interview transcripts with the information coded into themes. Secondly emergent themes were grouped into the four intervention categories of mitigation, adaptation coping and learning and plotted onto the Safe & SuRe framework in order to understand the context of the information with regards to the framework itself.

Ripple effect mapping (REM), which is a qualitative method for conducting impact evaluation using a diagramming process that represents connections hierarchically (Kollo*ck et al*., 2012), was then conducted for threats, system failure modes, impacts and consequences (Figure 5.1). The use of REM meant a visual representation of the implications of the threat and pathways to the consequences were provided. Both actualised and potential system failure modes, impacts and consequences that were discussed in the interviews are included in the REM as, at the time of writing, the pandemic remains an ongoing incident. Further information regarding REM is provided in Section 5.3.2. The second stage of analysis and creation of the REM was further validated by research colleagues. Although validation of the REM by interview participants would have been preferable, this may have compromised the anonymity of interview participants, and their willingness to discuss incidents openly, and was therefore not pursued.

5.3.1 Participant profile

A total of 11 interviews were conducted with water industry executives with one company providing two separate interviews. All respondents were UK water industry executives who were actively involved in the management of their organisation's COVID-19 response. Effort was made to ensure organisations represented by respondents were geographically spaced across the UK. This was so any regional differences in operating conditions and practices were accounted for.

To maintain confidentiality, quotations from interview participants that are presented in this chapter are referred to using a randomised number.

5.3.2 Ripple Effect Map

The REM shown in Figure 5.1 provides a visual representation of the relationship between threats and their consequences and highlights the complexity and interconnectedness that exists within such organisations.

The cascading effect of related system failure modes and impacts not only required organisations to implement additional coping mechanisms, but also resulted in social, economic and environmental consequences (Figure 5.1). The relative success or effect that each intervention had, dictated which impacts and consequences each organisation witnessed. The tiers, or ripples, show the threats, system failure modes, impacts and consequences that were discussed during the interviews with arrows used to represent both direct causal and possible links between the categories.

Figure 5.2 is used to show how threats, system failure modes, impacts and consequences that have been identified by the REM, can be further categorised on the four matrices as identified by (Butler *et al.*, 2016) . In the case of threats, the matrix can be used to identify threats that have occurred internally within the organisation, or externally, as well as those that occur gradually (chronic) or those that happen quickly and are usually unexpected or unpredictable (acute). With regards to system failure modes, they can again be categorised as either internal or external to the organisation/ system in question, as well as functional or structural. Impacts can also be categorised as internal versus external or chronic versus acute. However, consequences are categorised by their tangibility and directness.

5.4 Results

The following sections will discuss the threats, system failure modes, impacts and consequences that were discussed by participants in the interviews and identified using the REM.

5.4.1 Threats

As discussed by (Neal, 2020), the COVID-19 pandemic can be viewed as a 'threat multiplier', as the interaction with the ongoing weather event of reduced rainfall and higher than average temperatures, increases the complexity and cascading nature of the system failure modes, their impacts and subsequent consequences.

During April and May 2020 the UK saw higher than average temperatures with prolonged periods of reduced rainfall (Madge, 2020; Met Office, 2020), coinciding with the height of the first wave of the pandemic and national lockdown.

> *"Because lockdown coincided with dry weather [people were] out in their gardens, because there was nowhere else to go"* **Participant 191**

As a result water companies across the UK reported higher than ever levels of demand (Water Briefing, 2020), with changes to peak demand and distribution patterns seen across the UK.

> *"We saw demand increase by 350 million litres of water a day over a 36 hour period, which is huge."* **Participant 191**

> *"Demand for…the water service was through the roof. You will see that with everybody you speak to I'm sure*" **Participant 197**

Although the nationwide lockdown resulted in large scale commercial and industrial closures, for many organisations, the reduction in demand from the non-domestic sector failed to cover the overall increase.

> *"whilst commercial demand dropped off completely, water demand from domestic customers increased to more than cover…that commercial drop off."* **Participant 191**

Through the application of the Safe & SuRe framework (Butler *et al*., 2016), the outbreak of the COVID-19 pandemic can be classified as an external acute threat, due to the manner in which the virus progressed around the globe. However it is important to acknowledge that both pandemic influenza and emergent infectious diseases have both ranked highly on the UK risk register for many years now (Cabinet Office, 2017). This therefore pushes the event closer to the external acute/chronic threat boundary on the threat characterisation matrix outlined by (Butler *et al.*, 2016), and in Figure 5.2.

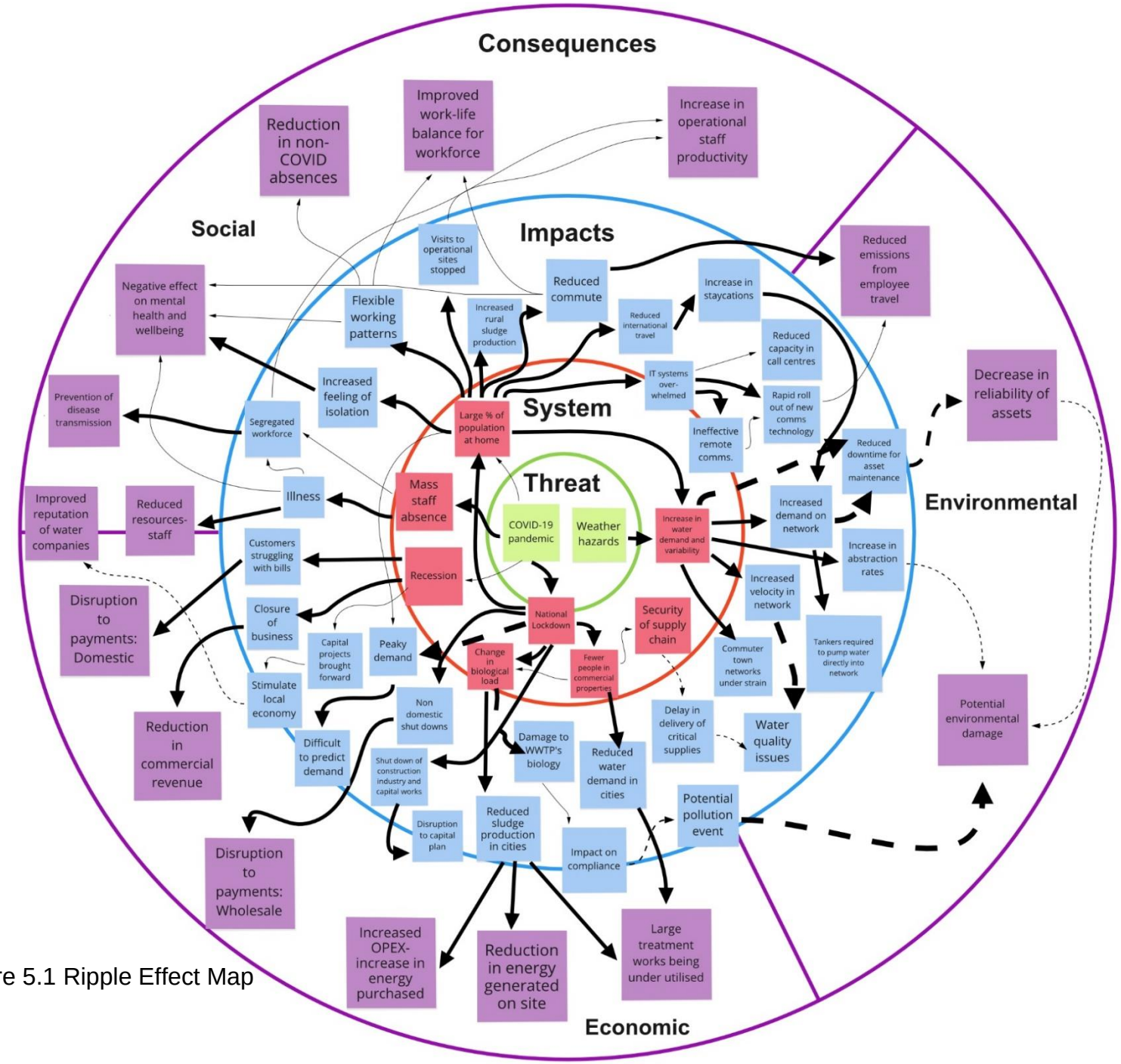

Figure 5.1 Ripple Effect Map

5.4.2 System failure modes

The Safe & SuRe approach and framework focusses on the middle-based analysis (middle states), which recognises that it is impossible to identify every threat to a system. The framework therefore instead focuses on failure modes of systems and their related impacts (Butler *et al*., 2016).

Middle states occur as a result of threats, and represent all potential modes of failure for a given system. Butler *et al.*, (2016) identify one of the main benefits of this approach to be that multiple threats that result in the same failure mode can be addressed with a single analysis, thus enabling a more comprehensive resilience assessment. Although it is important to note that whilst multiple threats can result in the same middle state, there are still many different ways in which a system can fail. Middle states can be further classified as either internal or external to the system, and functional (operational) or structural (Figure 5.2).

Figure 5.1 highlights eight system failure modes that occurred as a result of both COVID-19, the increased temperatures and reduced rainfall that occurred in the UK during the initial stages of the pandemic, and the interaction between the two.

> *"But then when you throw in the concurrent event…we had that period of really warm weather and we had a real demand surge and our network was just stressed…COVID wasn't driving that issue, that was a concurrent event*" **Participant 192**

Analysis through the REM also highlights examples of secondary failure modes, such as a change in biological load, that were not a direct result of COVID-19 but a result of national lockdown.

> *"we were seeing a real spike in terms of flow and load… which is tougher for the biology to adapt because with wastewater biology it can take 4-6 weeks before it will react to a different dynamic with the chemistry*" **Participant 201**

Figure 5.1 shows how cascading effects occur within a single tier or ripple as the effects of one failure mode result in failures in another area of the system.

Such interaction and connection between different system failure modes can also be seen through how a national lockdown resulted in a large percentage of the population at home, which in turn increased water demand and variability.

The cascading effects of system failure modes that were triggered by the threat of COVID-19 further emphasised the complexity of the sector, thus reinforcing Neal, (2020, p. 439) view that COVID-19 has provided a *"harsh lesson in complexity"* for water systems. This is as the external functional middle states of national lockdown (Figure 5.2) and a mass move to working from home, resulted in a change to previously predictable patterns of demand and use of the water and wastewater systems (Marshallsay, 2020). As the working environment extended into people's home and private spaces, the scope for external structural and functional failure modes also increased.

> *"we didn't have Teams when we first went home so we were reliant on tele-conferencing…and there were issues with regards to…accessing the central network"* **Participant 198**

> *"Yeah, so broadband capacity was the issue and there were some issues with…some of the broadband suppliers…early on*" **Participant 194**

Employee's access to broadband and equipment, a suitable working space and existing care responsibilities (Cotterill *et al*., 2020) had the ability to further impact overall organisational performance. This issue was particularly evident for customer facing roles and those who deal with confidential and personal information on a regular basis.

> *"Making sure they [staff members] have the right technology in place, particularly for customer facing roles… because a lot of those individuals maybe don't have a computer at home, even broadband. So, there was a lot of work and effort around technology"* **Participant 201**

> *"Yeah, and what we started doing was display screen equipment risk assessments…we said if you need a laptop riser if you need a new chair…you can have one. So, we started kitting people out semi-permanently to work from home…it's a combination of buying stuff and taking stuff out of offices and deploying it into the field or home space"* **Participant 194**

Such changes have for the first time altered the traditional dynamics of work and home life, with employers now requiring additional information on employee's personal life in order to maintain organisational performance, as the boundaries between the two continue to blur.

5.4.3 Impacts

Cascading impacts can be seen as the effects of system failure modes, that lacked appropriate adaptations, and disseminate through the system resulting in yet further social, economic and environmental consequences. Figure 5.1 provides a visual representation of how the impacts resulting from system failure modes both multiply in number and complexity as further interaction occurs across the system. The REM highlights the number and range of impacts that organisations were required to deal with which were a result of a large percentage of the population being at home. This is important to note as only one of the ten companies interviewed had previously planned for, or considered, the impact of a national lockdown on their operations.

> *"we had not factored in something like a lockdown previously"* ***Participant* 191**

> "*No. We didn't see a lockdown coming. I suppose it was mid-March before we really hit our speed and started to deal with a lockdown scenario."* **Participant 192**

> *"But I don't think we were thinking about lockdown at that stage, I really can't remember the specifics, but I don't think we were thinking lockdown"* **Participant 194**

Both Figure 5.1 and Figure 5.2 highlight the complexity of impacts witnessed by organisations and provide a visual example of how external functional system failure modes resulted in internal impacts. The increased demand on the network, which was linked to increased water demand and variability, and a large percentage of the population being at home and identified weather hazards, resulted in a reduction in downtime for asset maintenance. Which in turn has the potential to reduce the reliability of future asset performance.

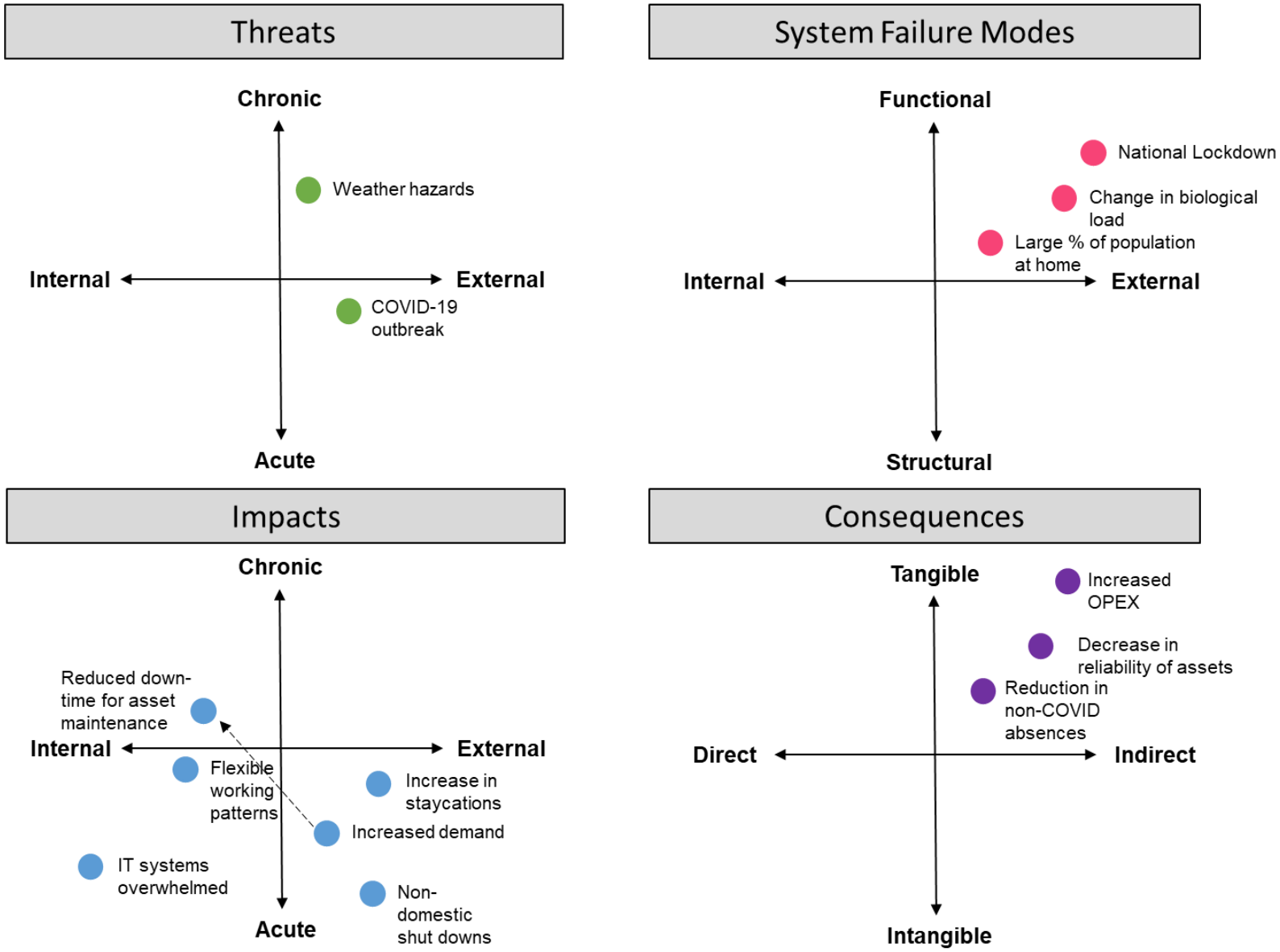

Figure 5.2 Example threats, system failure modes, impacts and consequences matrices. Adapted from Butler *et al*., (2016)

"that has been a real challenge for the teams to produce that amount of water every day, and because of that you have less down time to do the required maintenance" **Participant 201**

5.4.4 Consequences

The effect of organisational and operational impacts and their resulting social, economic and environmental consequences is shown in Figure 5.1. Again Figure 5.1 highlights the complexity of the system and its corresponding failure modes and impacts which were further exacerbated by simultaneous threats. Consequences are separated and grouped into social, economic and environmental in order to highlight the range of consequences related to the COVID-19 pandemic for both UK water companies and wider society.

Resulting consequences such as increases in operational expenditure (OPEX), reduction in commercial revenue, and increased work life balance for employees, are shown to be the result of multiple cascading impacts (Figure 5.1). Figure 5.1 highlights an imbalance in consequences with more social and economic consequences occurring, compared to environmental. The reasoning behind this is considered to be three fold. In many cases environmental consequences take longer to actualise when compared with social and economic, which are often much more instantaneous. Water sector regulators across the UK either completely stopped, or largely reduced environmental monitoring and sampling programmes during the first nationwide lockdown, therefore in many cases outside of wastewater site process data, environmental performance data simply does not exist. Finally, the interventions required to address the initial threat posed by the pandemic were predominantly socio-economic measures which has subsequently resulted in socio-economic based consequences.

5.4.5 Section summary

The use of the framework to design the interview questions and data analysis helped to create a clear structure and understanding of resilience and its related terms. Using the REM process in collaboration with the Safe & SuRe framework allowed for a clear visual connection between threats and their consequences to be produced. The REM provides practitioners and members of industry with a clear example of how the threat of the pandemic manifested into tangible impacts and consequences, whilst highlighting areas in which further interventions are required.

5.5 Identified interventions

The following section explores the intervention measures discussed by participants as part of their response, providing an insight into how the UK water sector responded to the COVID-19 pandemic.

5.5.1 Mitigation

Participants discussed mitigation measures that their organisations had taken in order to reduce the frequency, magnitude and duration of the COVID-19 pandemic on organisational performance and operational delivery. When referring to the organisational level, discussion around mitigation measures were concentrated on the existence of pandemic contingency and business continuity plans.

> *"Yeah, we had a pandemic contingency plan."* **Participant 192**

Although all participants referred to the owning of contingency plans, many described the "dusting down" of plans in order for them to more adequately address the threat that they were facing.

> *"I think it's fair to say that the plans probably covered 60% of what we experienced so it was a very quick rehash of the plans to try to understand what we needed".* **Participant 191**

Failure to account for the scale of the event, along with the associated impacts and consequences was another theme found through the data analysis. Although participants discussed the sectors history with regards to the need to prepare for and respond to previous global events, including infectious disease outbreaks, the scale of the COVID-19 pandemic is not something that organisations were prepared for.

> *"Whilst we have had BSE, bird flu, SARS and Swine flu … and had business continuity plans for all of them, [but] nothing on the scale of this"* **Participant 194**

Participants held the view that the failure of previous pandemic threats to materialise at scale in the UK, resulted in many organisations being caught 'off guard'. Past industry experience in dealing with, and learning from, both smaller routine and other large scale events was also referred to as actions that aided an organization's ability to implement measures to mitigate the threat they were now facing.

> *"The water industry is used to dealing with incidents so… it wasn't that big of a deal, we just flicked into incident mode and managed it"* **Participant 191**

All participants in the interviews spoke of the merits of the collaborative planning for the UK's departure from the European Union that had been carried out at the industry scale. A platinum level group which was set up and coordinated by Water UK focussed on issues such as maintaining supply of chemicals and other vital resources. As such plans already existed, they were then easily implemented in order to mitigate any issues that could have arisen from the pandemic with regards to the supply chain and more specifically security of supply.

> *"I think the industry itself had quite a collective response towards Brexit… so we just kicked back in and carried on the Brexit preparations that we had been doing, so that worked really well."* **Participant 191**

Other mitigation measures taken by organisations included preparations taken for mass absenteeism, which centred on training or 'upskilling' staff to operate treatment works, recruitment or university students to work in laboratories, and contacting recently retired operational staff to assess their willingness to return to work if required.

> *"we started to look at how many people we could train to carry out frontline critical roles in case our normal operators were unable to work due to COVID. And we trained over I think about a 2 month period about 300 staff who are in non-frontline roles to take on frontline roles if that would be needed…. Yeah, preparations started quite early for that work about January time I would say"* **Participant 198**

Operational interventions that were implemented in the weeks prior to the government mandated national lockdown, were also discussed by participants. Actions such as isolating operational teams with specific specialist skills, and minimising contact between different teams working on operational sites and in laboratories, with the aim of reducing point of transmission were all discussed.

> *"People weren't allowed in the control rooms they would have to do remote handover they would have to keep separation between the maintenance and ops [operations] teams so they wouldn't mingle…we did start to put in measures to stop people physically interacting as much as they would have done otherwise."* **Participant 191**

One participant referred to a mass work from home exercise that was carried out prior to the national lockdown announcement in order to test capacity of IT networks, as they acknowledged that *"IT was going to be our biggest risk, whether we could get people working remotely".* **Participant 193**

> *"We were discussing whether we should do a mass work from home exercise as we agreed on the Monday [2nd March] morning myself and a couple of directors went to see the CEO and said look we are going to do this working from home exercise. It's going to be quite disruptive, but you know on the horizon we can see lockdown coming".* **Participant 191**

Another participant spoke of taking proactive measures at the start of the lockdown period with regards to the organisation's priority services customers and the provision of bottled water.

> *"So, we've got about 3,000 customers on our customer care register …we would keep them informed of anything going on in their area …and we do a delivery of bottled water for over the winter months…. So, we did that again proactively at the beginning of April...so we made the proactive decision to deliver bottled water to those customers upfront"* **Participant 192**

Measures to try to mitigate the threat posed by prolonged higher than average temperatures and large proportion of the population being at home throughout the day, one company spoke of pre-empting increased in demand and deploying tankers to 'top-up" the water supply network in advance.

> *"We sent out our fleet of 30-odd tankers to pressurise the network in certain areas. [We] kept supplies going … under Covid restrictions…and customers didn't know"* **Participant 198**

Mitigation-based interventions such as 'up-skilling' staff to cover operational roles, and the collaborative efforts of the sector regarding the security of supply chain, proved effective at minimising the scale of the potential effect that the initial wave of the pandemic had on operational performance. Such efforts, which had resulted from learnings from previous industry based incidents (Industrial action 2018, Cryptosporidium outbreak 2015, Foot and mouth 2001, 2007), emphasises the importance of systematic learning for increasing the reliability, resilience and sustainability of systems.

5.5.2 Adaptation

Participants actively discussed the measures taken by their organisations to adapt working practices in order to reduce the impact of COVID-19 on

operational delivery. Within each response participants made a clear distinction between office and field-based staff.

> *"There were two parts to the way we dealt with it. Probably more than two parts. We've got field staff in operations and we've got office-based staff ... For field-based staff the world did change but not in the same way."* **Participant 195**

For those in field based operations, many of the routine activities stopped as a result of the uncertainties regarding the transmission of the virus. Customer visits were stopped with planned maintenance activities either scaled back or prioritised. This was to ensure social distancing and to reduce transmission of the virus to key personnel.

> *"Our capital works programmes were on going on, say our water treatment sites, or our wastewater treatment site. Our staff were nervous about these guys coming onto their site so there was a bit of protecting our own staff… more or less the entire capital works programme was stood down by the end of march."* **Participant 192**

Some participants referenced staggering shift patterns and trained staff to conduct remote handovers to reduce any physical interaction between key workers. Two participants explained how critical key workers self-isolated to ensure they would be able to continue operational delivery throughout the course of the pandemic. Site visits were also conducted remotely in order to reduce face to face contact with additional innovative approaches taken in order to adapt to this new way of working. Safety visits were conducted via phone with operators sharing site information via live video and drones.

> *"… when we came to commission some of our capital projects…we had some things we needed to get done by the end of the AMP [Asset Management Plan] so we had people using phones to guide us, we had a critical worker self-isolating… so we were commissioning via WhatsApp… Necessity is the mother of invention, you find a way of doing stuff."* **Participant 194**

Participants also provided examples of workforce adaptation where staff who had been identified and 'upskilled' to conduct critical roles were deployed to cover cases of absenteeism.

> *"there was one treatment works in particular where we lost 50% of the site staff so we did actually deploy a couple of reservists … [who] covered shifts."* **Participant 191**

For office based staff participants discussed working from home as an "overnight digital transformation" and a move towards a more agile workforce. However, it was the return to the office environment that was discussed within the context of adapting working practices. It was largely perceived that the office environment would adapt as a result of the pandemic and the need to continue social distancing. The ability of many personnel to be able to work effectively from home had also demonstrated that a flexible approach could be achieved. The use of digital technologies to conduct meetings would reduce the need to travel and office personnel could alternate the days in which they work from home and in the office to both limit face to face contact but also meet with other employees to reduce feelings of isolation and loneliness.

> *"I think there is an acceptance here that we will never be back working in the same way we worked before... The staff survey has shown us that there are about 100… staff that are keen to get in back to the office, 450-470 [want]… the ability to work from home as well as some time in the office and… [some] who just don't want to go back to the office at all. The vast majority are in the middle… we will never be back to having 100% of people in the office 100% of the time, that's not going to be the case."* **Participant 192**

Participants discussed many adaptation measures as reactive rather than planned. This was largely in response to the scale of the pandemic and the rapid timescales with which the country went into a lockdown situation.

> *"Yeah, it largely went to a reactive position and everything was risk assessed to say, do we really need to be doing that activity at the point or can we hold it off? Especially, in the early days we risk assessed each activity then said do we feel now as lockdown rules change as the peak of the outbreak began to tail a bit, we started looking at them with a risk*

based approach and we started to say can we start to feed them back in? Or do we still need to exercise caution? That is still going on."
Participant 197

During the initial stages of the pandemic, there was a great reliance on the use of risk assessments to adapt to the immediate situation. However, applying the risk management approach to achieve future resilience created multiple challenges as a result of uncertainties regarding virus transmission and the possibility of further lockdowns.

Changes to the incident management structures of teams within organisations that were tasked with facilitating a response, was also highlighted as an adaptation measure. This was as the traditional operational roles required for operational incidents and events, were no longer a focus, and were instead replaced by individuals from Human Resources and Communications This was particularly experienced at the Bronze, operational level of incident management rather than tactical (Silver) or strategic (Gold) levels.

"the bronze teams in normal operational activity would have been sort of geographically split and they would have been very much operationally focussed. Whereas what we found ourselves doing this time was that the bronze teams were functional or directional, so we had HR, we had an asset delivery we had a comms [communications] team so that's the way the bronze teams were structured which is completely different to an operational event." **Participant 192**

5.5.3 Coping

Participants outlined multiple coping measures and mechanisms that were implemented to cope with the impacts of the COVID-19 pandemic.

Across the interviews the most prevalent coping measure that was discussed was that of the move to working from home for a large proportion of office based staff, with many participants reporting the relative success of the move.

> *"You know shifting thousands of people to work from home pretty much over night with hardly any operational impact was really good."* **Participant 194**

Yet the move was not without its challenges, with many participants reporting issues and associated disadvantages to the new way of working. The majority of such disadvantages centre around employee's wellbeing and meta health due to feelings of isolation or the inability to separate work and home life.

> *"…It's been hard for [people who work from home] to create boundaries with how they work… They don't have a commute; they don't have an effective start and they don't go home at night. I was talking to one of my colleagues, a guy on my team said [he] misses the train journey and I said, 'you are kidding' and he said, 'no I miss it because it was closure for the day."* **Participant 194**

Many participants therefore spoke of mechanisms implemented at an organisational scale to aid employee's ability to cope with regards to their mental health and wellbeing.

> *"…we were really conscious about people's mental health and the fact that some individuals were now working from home and potentially not engaging with individuals on a day-to-day basis. Particularly if you are someone that lives on their own… We are actually really mental health aware, but I think we took it to another level with the lockdown."* **Participant 191**

The use of effective and efficient communication was also considered to be a large part of the organisation's ability to cope with the pandemic and new ways of working by participants. As the threat and its associated impacts continued to develop, effective lines of communication put in place across organisations were discussed as coping mechanisms.

> *"…the communication protocols we put in place as a business, exec level down to the field teams have been the thing that have given us the ability to cope. There have been lines of communication [and] they have been effective because information has travelled quickly from source to action."* **Participant 197**

The increased use of video calling technology such as Zoom and MS Teams was also repeatedly spoken about in the context of coping, both with regards to conducting everyday tasks that could no longer be done in person as well as providing a platform for communication that field staff have the ability to access as well as office based staff.

> *"I think in a way the use of Zoom or Teams …[is] less personal because you are on a screen and not physically in a room with someone but what I've found is…it actually makes it easier to communicate with large numbers of people... During the lockdown I've found I did this weekly for the first few months and I'm doing it fortnightly now... So that's definitely worked well, and I think it's changed other practices that we will keep regardless of the restrictions."* **Participant 195**

The pre-existing status of remote field workers in the water industry was also discussed in the context of coping. Within the water industry, many field workers have the equipment and technology to be based out of their van and therefore do not require access to office spaces. Such pre-existing modes of working along with pre-existing remote network control were considered crucial to the ability or operations and specifically operation staff to cope.

> *"Our field staff are already remotely based so they don't come into the depots and offices. They work out of their van, [where] they have their laptop and they don't have to go into anywhere to be able to log onto anything so … they were relatively safe in coming to work every day, because their office was their van… They would by-and-large either be on site on their own or with one other person."* **Participant 195**

Changes to usage patterns of the water and wastewater networks resulted in the requirement for both adaptation and coping mechanisms that organisations had not previously considered. With the mass move to working from home pushing some IT systems to the brink of failure with some organisations requiring more time than others to extend bandwidth capacity and to ultimately enable employees to effectively work from home. Such advances in technology have not only provided mechanisms in which operational staff could provide technical knowledge and assistance to on-site employees without being physically present but have also provided the capability for large organisations

to maintain successful and effective lines of communication with their workforce when spread out across large geographic areas.

5.5.4 Learning

All participants discussed learnings that have so far occurred from the pandemic, with a view that there are many more still come.

The notion of 'realisation of risk' and the need to *"expect the unexpected"* ***Participant 197,*** was mentioned by multiple participants in reference to lessons learned. As the industry failed to adequately prepare for the scale of the pandemic, one participant suggested the need to now evaluate the organisations risk register in order to test other assumptions they may have made for other potential threats.

> *"what I'm recommending to the board…is that we really seriously need to look at our risk register and test all our assumptions out again, because if we were slightly wrong about flu pandemic, we weren't expecting lockdown, what else are we slightly wrong about"* **Participant 193**

The failure of many organisations to see and acknowledge a national lockdown and the associated impacts and consequences as a credible scenario that would result from a pandemic threat, resulted in many companies miscalculating the associated impact.

> *"[The pandemic] necessarily wasn't classified in terms of impact in the right way. So, from that perspective it wouldn't have been seen as one of the ten or twenty corporate risks...We've not really lived in that type of risk materialising…it's probably caught a few companies off guard in that respect"* **Participant 201**

The success of the mass move to working from home has resulted in a changing view of emergency management with multiple participants discussing ending contracts for backup physical office spaces.

> *"our disaster recovery plan for the head office was if it burnt down you would move to a separate office. So, you paid for a disaster recovery office…but clearly now we have just said well actually if it burns down then we just go home. So, we stopped that contract."* **Participant 198**

The mass move to working from home has also provided an opportunity for organisations to redevelop how traditional office spaces are both physically and mentally, viewed, approached and utilised. The traditional view of 'presenteeism', and the idea that office based employees are at their most productive when sat at a desk in a communal office space, has been brought into question by the new way of working.

> *"Yeah, and other lessons learnt really, I think it's given us a great insight into we have been very traditional in the way that we run our business you know desk time and office space is seen as a measure of effectiveness in some ways, but we have performed extremely well without all being crammed into a glass box in the middle of [location]."* **Participant 197**

Such changes to ways of working have also provided an opportunity for organisations to redesign office spaces and to create an environment for more specific purposes.

> *"…we are now looking at reducing the occupancy of our office environment, but not just to reduce the occupancy but to create a better environment. Rather than think oh well we have to come into work, well no you don't have to come in because you can work from home if that suits you…So when you come in you are coming in for a reason to meet your team or do a workshop or work through some idea. You are coming in for a reason and you like it when you are there rather than coming in like a battery hen everyday…So that's definitely something we have learnt really."* **Participant 195**

As previously outlined, planning done in advance for the UK's departure from the European Union was considered a success in regard to preparation. The success of the approach adopted, has resulted in the knowledge that such a level of collaboration can benefit the industry as a whole.

"No definitely I think that's been really good, even just from a sense check of are you doing the right thing. I think again that was originally set up that format for Brexit, but we used that same structure for this, and it worked really well." **Participant 195**

"Industry level liaison I think has come on in the last few years and we have broken down a few barriers with actually recognising that there is some strength in numbers and that it's best to share best practice" **Participant 196**

However, as always it is important to take into account the context in which the sector operates. Water and wastewater providers in England and Wales are privatised entities that operate within a competitive and highly regulated market. League tables published by industry regulators, the current five year regulatory periods, and the resulting continued race for the top were all cited by some participants as a barrier to past collaboration. Such context therefore has the potential to impact organisations degrees of freedom, and access to resources, if they are to effect true change (Cook and Nemeth, 2010)

5.5.5 Section summary

This section has helped to identify mitigation, adaptation, coping and learning measures that were identified and implemented by organisations as part of their initial response to the COVID-19 pandemic. Cross industry preparation, collaboration and collective working were all found to be successful and effective at helping to minimise the impacts and consequences associated with the pandemic. With many participants expressing interest in actively pursuing such options for the future and highlighting the need to continue to emphasise the benefits of such modes of working to industry regulators. Pre-existing pandemic plans were identified as inconsiderate of the scale of the pandemic, which has resulted in some organisations now re-evaluating other existing business continuity and response plans. With one participant reflecting that wider risk management approached warranted an overhaul. However there remains a continued focus on the identification, impact and likelihood of threats at the corporate and organisational with the sector continuing to focus on a traditional risk management approach to such issues. Such an approach

historically results in a tendency to assess the impact and consequence of single threats and hazards, and thus single threat based mitigation measures.

The inability of the industry to plan for issues at scale and those considered ‘unknown’ hampered some organisation’s ability to mitigate some threats. Overall, the interviews reflected the sector wide view that UK based water companies did well to respond to the pandemic and maintain required performance of critical services. This is as the COVID-19 pandemic has provided the water sector with an insight into the impact and consequences associated with an external acute threat and the resulting internal issues as it interacts with an external chronic threat. It is therefore important that organisations do not become complacent and fully acknowledge and embed new knowledge in best practices if the resilience of the sector to multiple threats and hazards is not only maintained but increased.

5.6 Chapter summary and key messages

This chapter has presented the results of interviews conducted with UK water industry executives, on their organisational and operational response to COVID-19.

In answering the research questions that were posed at the beginning of the chapter in Section 5.1, it was identified that:

- The Safe & SuRe framework can be used to create and design a thorough research methodology. Use of the frameworks four phases of intervention to structure interview questions and analysis provided a clear outline of how organisations responded to the COVID-19 pandemic, as well as an indication of the organisation’s current levels of resilience.
- Overall, the UK water sector performance and response to the COVID-19 pandemic was found to be adequate with only a small number of organisations reporting a reduction in initial system performance.
- Industry wide collaboration, experience in incident response, robust IT structures with experience in remote working, isolation of operational staff

and the use of technology were all found to have contributed towards the UK water sector's ability to respond to the pandemic.

- The COVID-19 pandemic has highlighted areas in which additional interventions could be put in place the increase individual organisation and sector wide resilience.

Chapter 6: Development of a resilience based mobile application

6. 1 Introduction

Chapter 5 explored how a resilience based theoretical framework, in this case the Safe & SuRe Framework, could be used to assess organisational resilience. Here an example was provided on how an existing resilience based framework could be applied after an event through desk based analysis. However, questions remain around how the framework can be adapted for daily use at the operational level, whilst contributing to proactive resilience planning processes.

This chapter aims to explore how a resilience based mobile application can be developed using the Safe & SuRe framework. The application has been co-developed with members of staff from NW workforce using a form of participatory action research with input provided at multiple different stages.

This Chapter addresses Objective 4 which posits the following research questions:

i. What should the central aims of the application be?
ii. What platform should an online resilience application be developed on?
iii. Which level of the workforce should the application be tailored too and why?
iv. How should the results/data be displayed?
v. How can the application contribute towards the development of a resilience culture?

The Safe & SuRe framework was used as the theoretical framework which the application is based upon, with the application itself developed from the Safe & SuRe Decision Support Tool (Sweetapple *et al.*, 2019) which was developed by the Safe &SuRe team at the University of Exeter in collaboration with Scottish Water. A series of in-person and online focus groups were designed to facilitate the co-production process and provide validation of the results.

The remainder of the chapter is structured as follows; Section 6.2 introduces the resilience based tool and how it relates to the Safe & SuRe framework, and the initial version that was developed. Section 6.3 discusses the focus groups that were conducted with the purpose of introducing the Safe & SuRe framework and tool to the NW workforce. Section 6.4 introduces the mobile app, it's development, and discussion relating to the results from the associated focus groups. Section 6.5 then provides a conclusion to this chapter.

6.2 Development of a resilience based tool

As discussed in Chapter 1, 2 and 4 the Safe & SuRe framework is a theoretical resilience framework that helps users to identify connections between threats and consequences, whilst aiding identification of opportunities and priority areas for intervention. Although the framework can be used for desk based analysis, as demonstrated in Chapter 5, it is considered that the development of an interactive tool would aid regular use at the operational level, and further operationalisation of the resilience concept.

Solymosi and Chataway, (2019), discuss the idea that increasingly, the justification for social scientists incorporating apps into their research is due to the ability to capture data about social phenomena in-situ. They continue that people are increasingly interested in what is considered to be 'everyday real world behaviour' and how this can be used to inform or impact on going research. If resilience is considered to be something that a system does, rather than something it has as stated by Hollnagel, (2015), then such 'everyday real world behaviour' has the potential to not only impact overall system performance, but contribute to how resilience and resilience based actions can be improved. As discussed within Chapter 3, participatory design was used in this research in order to involve users throughout the design process, from identifying needs, to developing and testing the designed product. The intention behind the use of participatory design is to create a sense of ownership amongst users and empower them as stakeholders (Virani *et al.*, 2021). The

participatory approach used in this project was divided into three phases: framework review, app testing, and focus group discussions.

One of the key areas of the Safe & SuRe framework is the facilitation of identification of interventions or measures that can be used to minimise the impacts and consequences of identified threats or hazards. This refers to mitigation, adaptation, coping or learning measures that can be implemented by the organisation to further the ability of the system to maintain the required level of performance independent of operating conditions. Or more simply put, to increase the resilience of the system. The aim of the tool is to help users identify interventions as well as how they are connected to other areas of the framework. Table 6.1 shows the direct connections that exist within the tool and provides the framework for how in-direct connections are calculated.

Table 6.1 Connections within the tool

From	**To**
THR	MIT
THR	SYS
SYS	ADA
SYS	IMP
IMP	COP
IMP	CON
COP	CON
LEA	THR
LEA	SYS
LEA	IMP
LEA	CON

THR- Threats

MIT- Mitigation

SYS- System Failure Modes

ADA- Adaptation

IMP- Impacts

COP- Coping

CON- Consequences

LEA- Learning

The use of the Ripple Effect Map in Chapter 5 provided a visual representation of the connections between threats, system failure modes, impacts and

consequences. However, the REM only provides an insight into a snapshot in time for a specific case study and requires a high level of user input and understanding of the framework. It was considered that a tool that could be used to store issues with system performance and possible future intervention as operators identified them, would aid the transition towards a more resilience based approach to system management.

This research has further developed the Safe & SuRe framework tool in Microsoft Excel VBA through a co-collaboration process with members of the Northumbrian Water workforce, before the concept was further developed into a mobile app using Microsoft Power Apps. An outline of the methodology for development is provided in Figure 6.1.

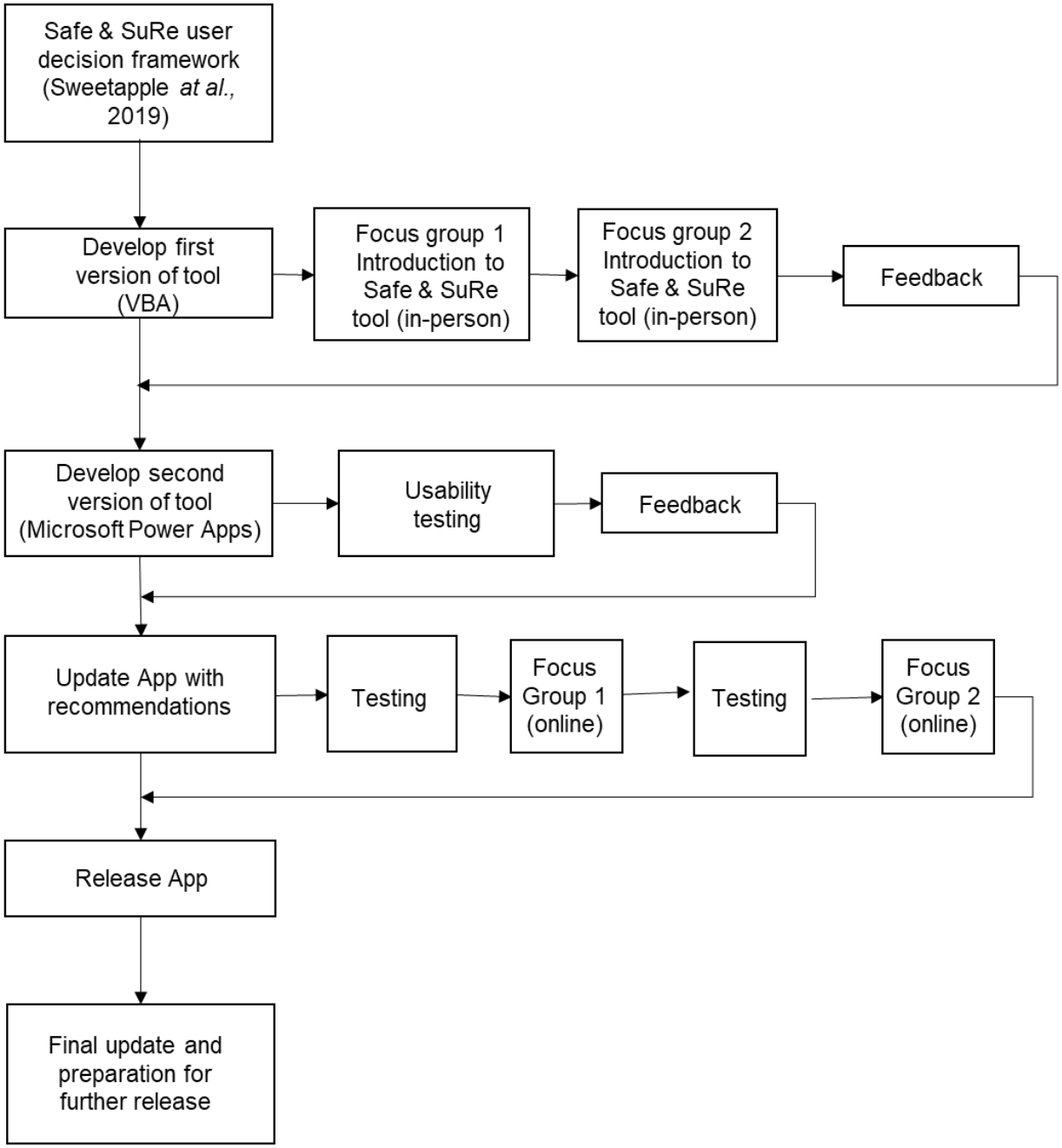

Figure 6.1 Methodology for development of tool

6.2.1 Development of tool in Microsoft Excel VBA

Considering the success of the Safe & SuRe Decision Support Tool (Sweetap*ple et al*., 2019) developed in Microsoft Excel VBA, it was agreed that the first version of this resilience tool would also be built using VBA and housed in Microsoft Excel. This allowed the researcher to gain a better understanding

of, and become more familiar with, how the tool works both in relation to the framework and user interface.

Microsoft Excel was chosen based on the wide reaching availability and user knowledge of Microsoft programmes across the UK water sector, and within NW. The tool itself is saved as a Microsoft Excel file and can be easily shared via an email attachment. Any user with access to Microsoft Excel is able to open and edit the file. The user interface is created through an image and a series of interactive buttons and drop down menus, which allow the user to navigate through the file, whilst inputting data. The tool homepage is shown in Figure 6.2

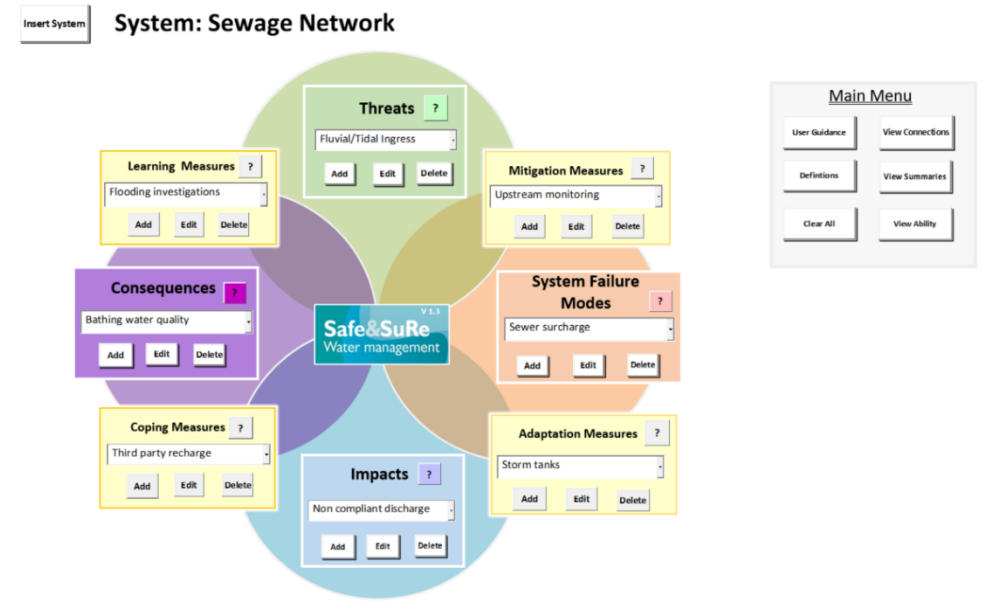

Figure 6.2 Homepage of resilience based tool.

A main menu on the right hand side of the screen provides users with short cuts via buttons to help navigate through the tool. It is here that users can navigate to user guidance, definitions used within the tool, and view results. All aspects of the tool are stored within the Excel file on separate sheets as shown within Figure 6.3.

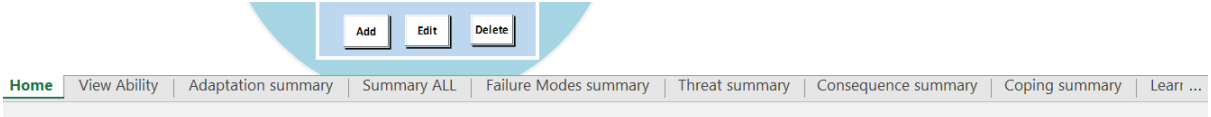

Figure 6.3 Sheets stored within Excel document

Microsoft VBA is used to create Macros that in turn automate tasks within Excel and create connections between all aspects of the document. Whilst users input and edit data via User Forms (Figure 6.4).

User Forms provide users with the ability to enter a title, description and comments, as well as to select connections between threats, system failure modes, impacts and consequences and identified intervention measures (mitigation, adaptation, coping and learning) (Figure 6.4).

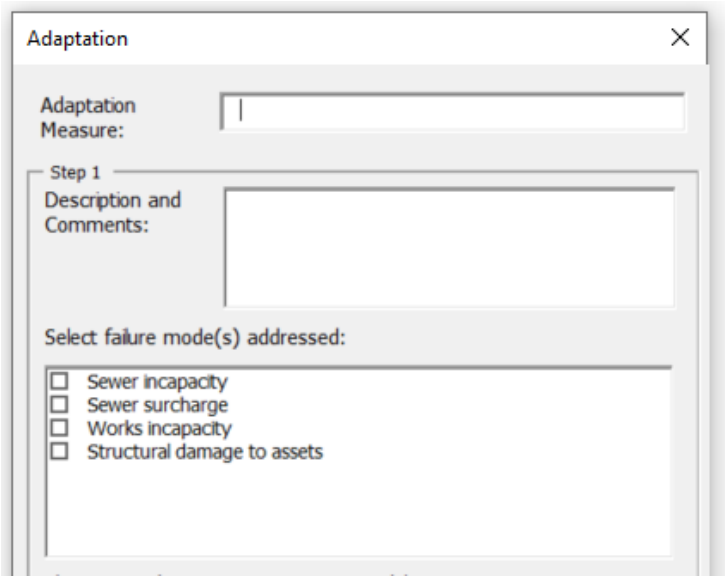

Figure 6.4 User Form with ability to select connections.

Data is stored in Excel sheets as lists, with connections stored in a matrix where 0 represents no connection, and 1 a connection (Figure 6.5).

	A	B	C	D	E	F	G	H	I	J
		Unknown	Fluvial/Tid	Third party	Poor main	Developer	Consumer	Consumer	Rain	
	Hotspot analysis	0	0	1	1	1	1	0	0	
	Customer education	0	0	0	0	0	0	0	0	
	School education campa	0	0	0	0	0	0	0	0	
	CCTV surveys	0	0	0	1	1	1	0	0	
	Upstream monitoring	0	0	0	0	0	0	0	1	

	A	B
1	**Impact**	**Description**
2	Flooding of assets	
3	Flooding of customer properties	
4	Poor treatment quality	
5	Non compliant discharge	
6		
7		
8		
9		

Figure 6.5 How data is stored in Microsoft Excel

Results are presented in the tool as graphs and charts (Figure 6.6, Figure 6.7) which are automated using Macros. Results can be accessed via the main menu on the home page.

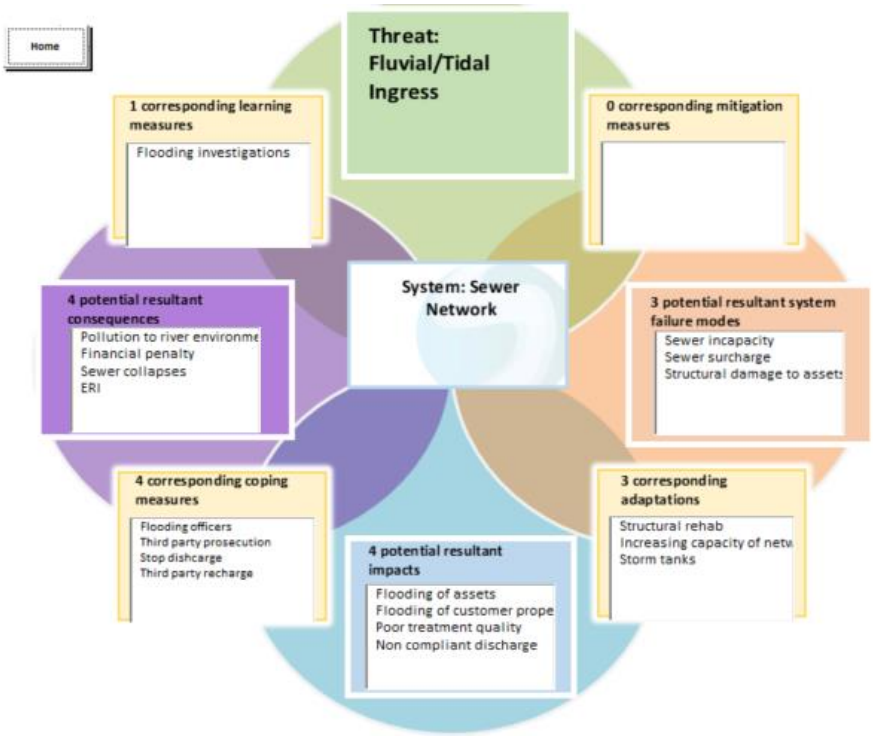

Figure 6.6 Graphic listing connections between selected threat and other framework categories.

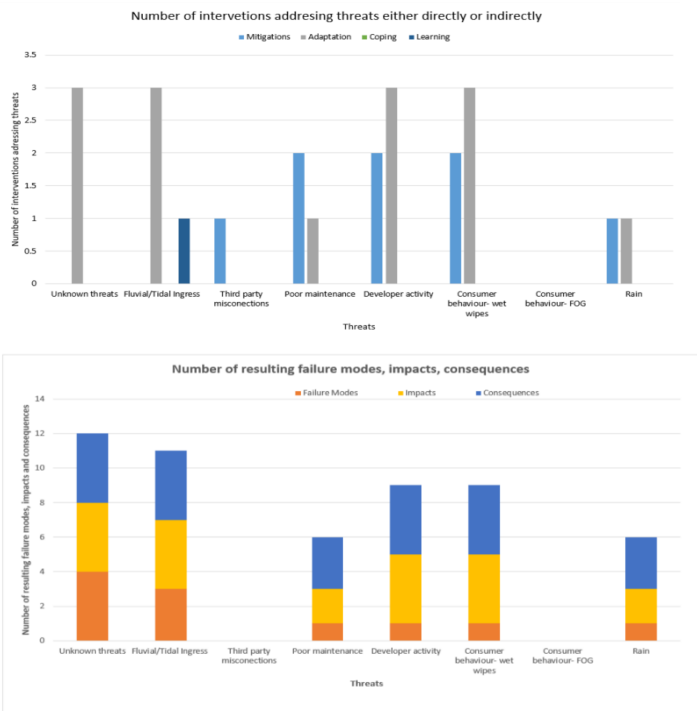

Figure 6.7 Graphs created to display results

Users can select a specific value from the eight categories listed in the framework via the homepage and view the connections (Figure 6.6) or the number of relating interventions, or the number of associated threats, system failure modes, impacts or consequences.

Following initial informal discussions with members of the NW workforce and Ken Black (industrial supervisor), it was decided that the first version of this tool would include an option for users to enter the perceived ability of, and timescale required by NW to implement identified interventions (Figure 6.8). This information would be scalar and entered via the UserForm for each of the interventions (Figure 6.8). Ability would be rated on a scale of 1-5 with 1 representing no ability and 5 complete ability. Timescales would be defined as 0-2 years, 2-25 years and 25 years plus, which is in line with current planning timescales used by the organisation. As the tool was to be targeted towards operations based staff it was considered that this would provide a ’bottom up’ insight into existing methods of operationalisation.

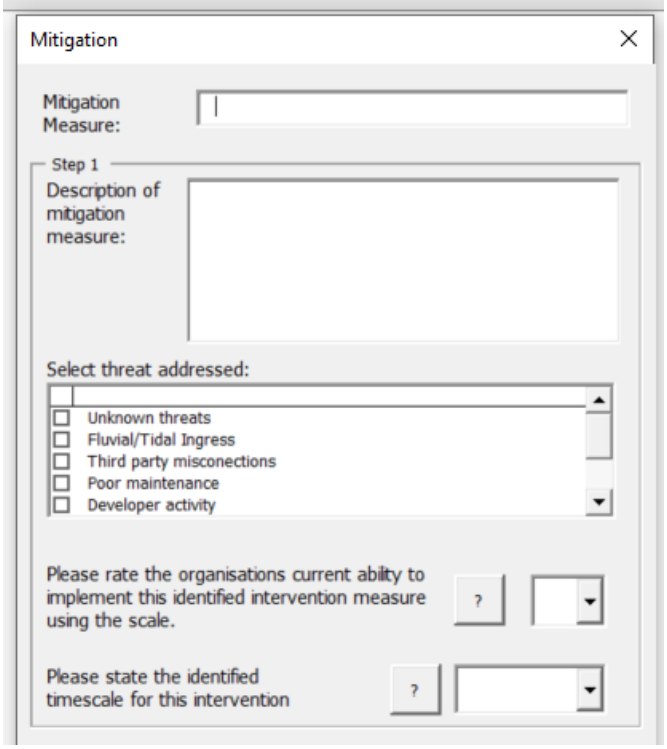

Figure 6.8 UserForm with option for ability and timescale

Following the development of the initial version of the tool it was agreed that a focus group would be carried out with the aim of gaining an understanding of how the framework could be introduced to NW workforce as well as the suitability of the tool itself. This approach also allowed for a focus on the social systems present within the organisation.

Focus groups (in-person)

As outlined in Chapter 3 Section 3.7.2, an initial in-person focus group was conducted with members of the NW workforce from the Asset Management directorate. The second focus group consisted of members of staff involved with wastewater operations. The focus group was designed to assess the suitability of the Safe & SuRe framework and tool as well as introduce participants to a new way of approaching the topic of resilience.

The first stage of the focus group consisted of a presentation provided by the researcher. The presentation covered an introduction to the concept of resilience, why resilience is important to the UK water sector, and examples of the influence of social systems on overall system performance. Participants were then introduced to a group task in which they required to use a water treatment works as an example and think of threats, failure modes, impacts and consequences that would affect the treatment works, writing each one on a post it note and attaching to the corresponding area of the framework image on the table. Participants were later required to add interventions to the image. Further activities consisted of drawing connections between threats, system failure modes, impacts and consequences and the interventions that had been identified, as well as rating interventions on an impact vs. ability axis. Images taken during the initial focus group are shown in Figure 6.9. During the session, participants were also provided with an introduction to the tool itself.

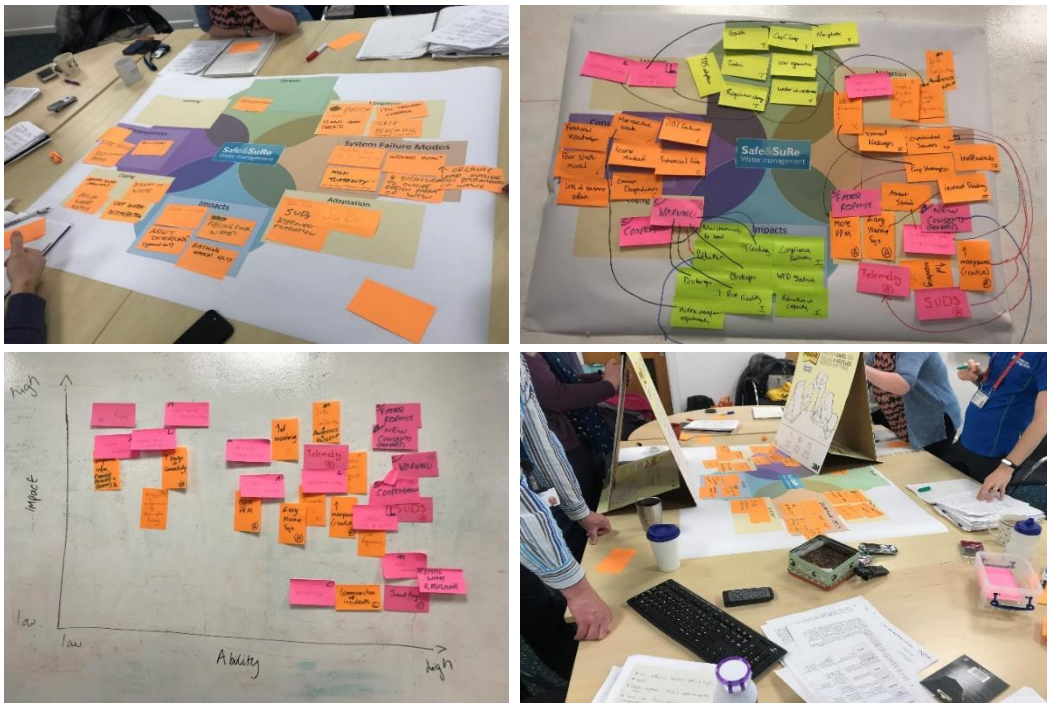

Figure 6.9 Activities completed during in-person focus groups.

Discussion during the focus groups centred around the current approach to resilience taken by the organisation as well as how the Safe & SuRe narrative

could be introduced and applied across the wider organisation. Informal feedback at the end of the session centred around the tool and usability. Participants suggested that although everyone in the room felt confident at using the tool whilst it was based in Excel, the requirement of having one master file limited usage as only one person would be able to access the information at once. Reference was also made to the risk of over complicating the tool and the need to identify what the core aim of the tool would be.

6.4 Developing the app

Following feedback from the initial focus groups and informal discussions with industrial supervisor Ken Black and other members of the NW workforce, it was agreed that the tool would be developed into a mobile app. Here the app could be accessed by staff working within operations, who do not have regular daily access to a laptop or desktop computer, as well as those who held office-based positions.

As discussed in Chapter 3, Section 3.7.2, Microsoft Power Apps was decided on as the most suited software programme for the development of the application. Recent developments with Microsoft itself, regarding the functionality and increased possibility of connections with both Microsoft and non-Microsoft based programmes (Akhigbe, 2021), along with changes to how NW worked, meant a Power Apps based application could be both easily shared across the organisation and connected to existing systems. This also included the option for multiple users to access the application at once, as well as results to be stored in a format that already had widespread use across the business.

Following both informal and formal feedback from the initial focus groups, the decision was made to focus the aim of the app on the input of identified threats, failure modes, impacts, consequences, and interventions as well as their connections.

The app interface is built in Power Apps with all data stored in SharePoint lists. Results can then be either viewed directly in SharePoint lists or through the Power Bi interface that has also been created. Features available on the app include a video introducing users to the Safe & SuRe framework and their approach to the concept of resilience with links to further information, as well as user guide ‘how to’ videos on adding, editing and deleting data (Figure 6.10).

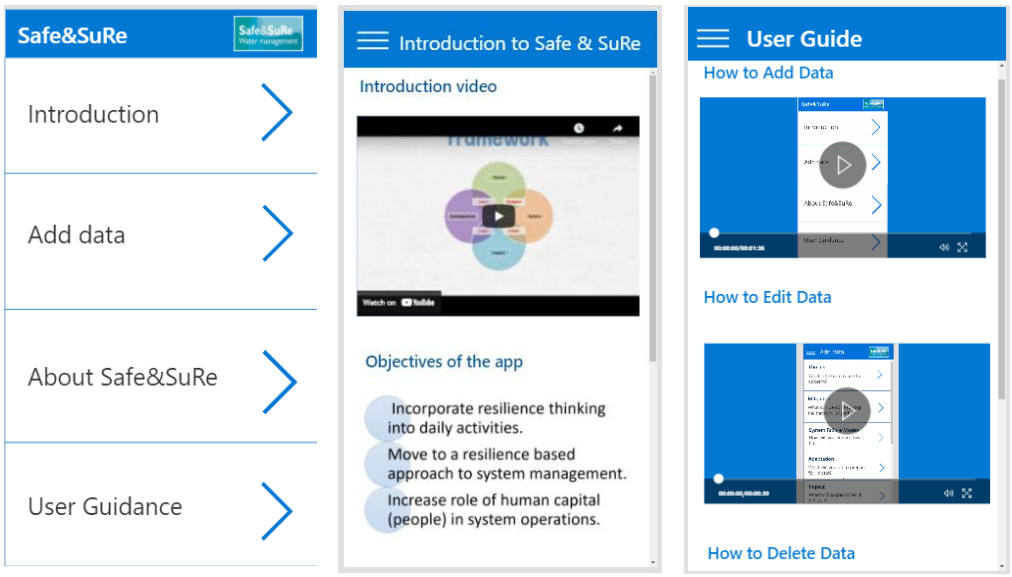

Figure 6.10 Further information available on the app

Users enter data via the home screen and by selecting ‘Add data’. Users are then presented with the list of categories which are split into ‘problem’ and ‘actions’ (Figure 6.11).

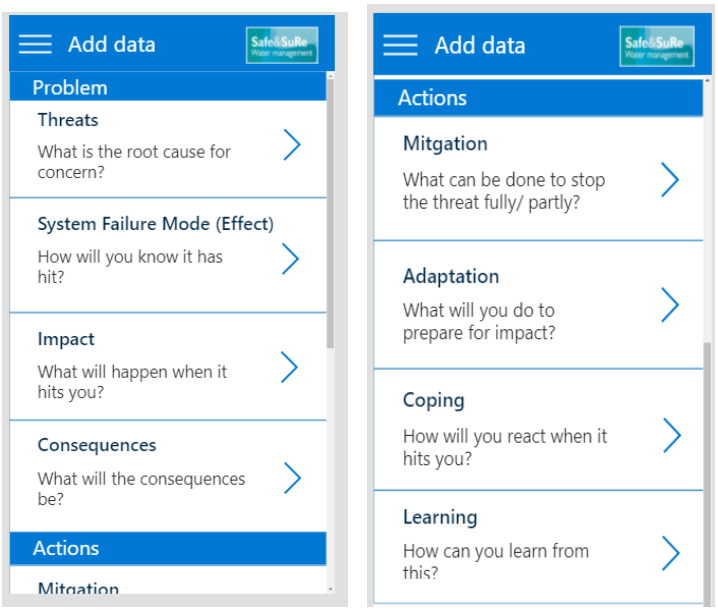

Figure 6.11 Adding data via the app

Once users have selected the relevant category they are presented with that category's homepage. From here users can view the data that has been previously added to that category or select 'Add New' to add data (Figure 6.12). The 'Add New' screen provides users with prompts to help them enter the relevant data, along with the ability to select relevant connections with other categories or interventions, and add image based attachments.

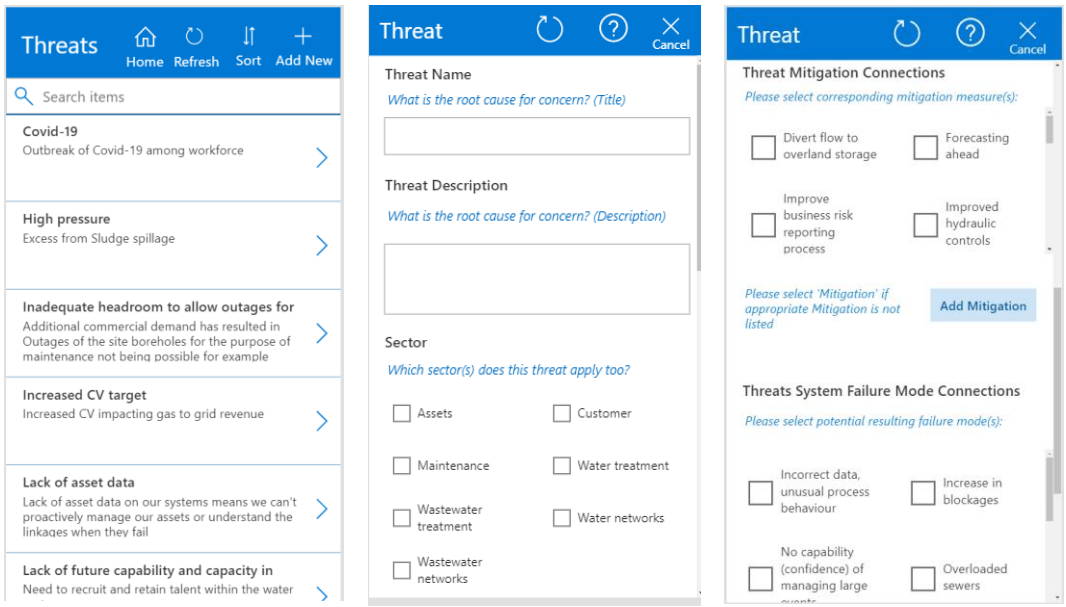

Figure 6.12 Adding data

As previously mentioned, results for the app are stored in SharePoint lists (Figure 6.13) which can either be viewed directly in SharePoint itself, or through the Power Bi dashboard (Figure 6.14) that was created. The data is split into categories within SharePoint with title, description, sector and connections along with the details of who entered the data and when automatically collected and stored by Microsoft. Any attachments that may have been uploaded are also stored here.

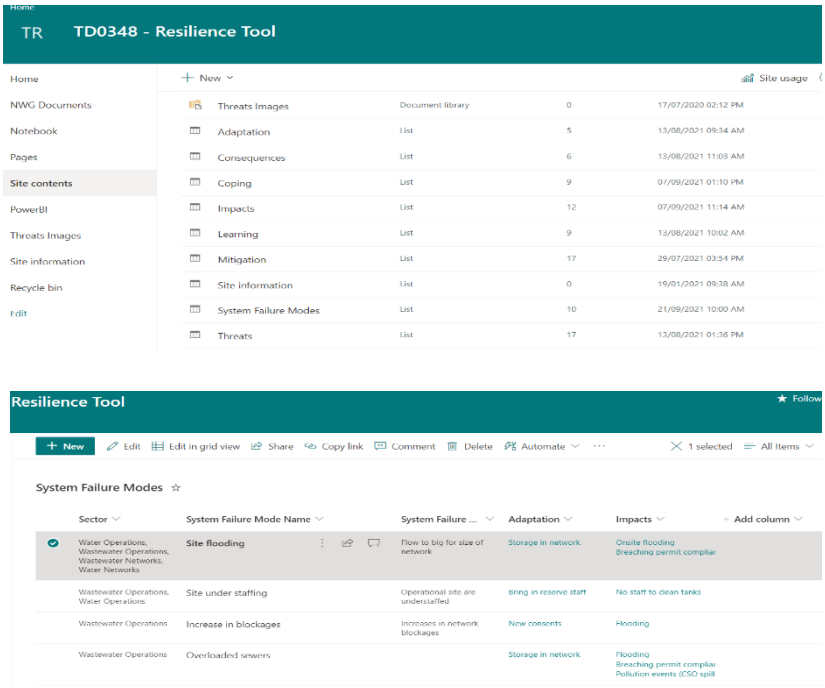

Figure 6.13 Data stored on SharePoint site

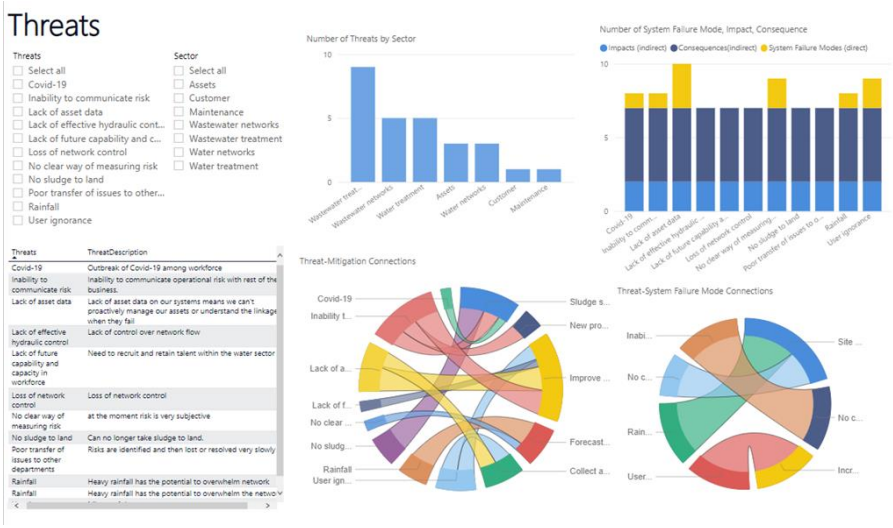

Figure 6.14 Example of Power Bi dashboard

6.5 Focus groups (online)

As outlined in Chapter 3, Section 3.7.2 a second set of focus groups were carried out online using Microsoft Teams, once the initial version of the app had been developed. A group of eight participants were invited to take part in the series of online focus groups. Participants were selected by industrial supervisor Ken Black and were asked to test the app before the initial focus group. Participants consisted of operators, site team leaders and asset management technicians.

6.5.1 Focus group feedback and discussion

App usability and user experience

Feedback gained from the focus groups with regards to the ease of the physical use of the app centred around data input. Overall participants found the app to be easy to use and enjoyed the use of videos, especially to introduce the concept behind the framework and app itself.

> *"It's very straightforward and it's you know, the introduction part [video], especially, I thought was excellent*"

Similarities between this app and an app already in use across the business to record health and safety information were also made. Such similarities were considered to create a sense of familiarity with users and increase ease of use.

> *"it's really easy [to use] and similar to the way we use the Coruson app"*

Multiple participants suggested making changes to how connections are identified and saved within the app. The initial version required users to navigate to a separate page and select options from a multi-choice dropdown menu. When selections had been made, users were also required to select a 'X' labelled 'cancel' in the top right corner of the screen to be able to move onto the next section of the data input. Feedback from the focus group showed that

users found closing out of this more complicated and would prefer and alternative to the drop down boxes.

> *"Also, to close something down there's a… cross…[and] you then have to come back out of it, you can't just say continue, you to have to hit the cross to then go back to the next stage"*

Following such feedback, a later version of the app was developed with the drop down menus replaced with check boxes, and with connections data added to the initial add data form. This contributed towards the simplification of the data input process for users.

Similar to the issues with inputting data for connections, as part of the initial version of the app to submit a form for the 'Add data' section of the app, users were required to select a button on the top right of the screen displaying a tick (Figure 6.15). Once the button had been selected users were required to manually exit the screen to go back to the home screen of the app. A later version of the app replaced this with a 'Submit' button located at the bottom of the form which then automatically navigated back to the homepage of the category users were in (Figure 6.15).

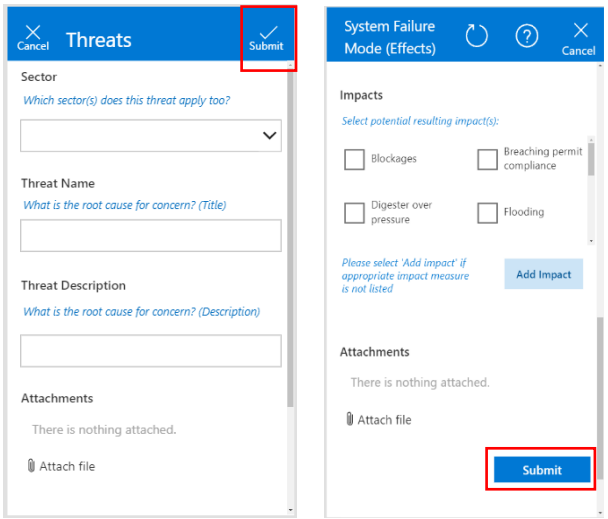

Figure 6.15 Change from 'tick' to submit button

The need and requirement from users to have more simplified paths of navigation within the app relates to a discussion that was had between participants on the 'number of clicks' required by users at any one time.

> *"One of our jobs is to challenge how many clicks to get to the end, as well… One of the criticisms we get for the Maximo app from maintenance…is that sometimes it can be 15 minutes' worth of clicking to close a… maintenance job whereas before it took them two or three [minutes], because they didn't capture any data…and that's [impacting] productivity. So, we've got to bear that in mind as well, what's the fastest way of capturing the data"*

Here although discussion was based around an alternative application that was being developed for operational data collection within the organisation, learnings based on the balance between the need to collect accurate data without negatively impacting other areas of user's daily activities can be applied.

Terminology and understanding

Terminology and language used, as well as definitions and understanding, was also discussed by participants during the focus groups. Participants felt strongly about the need to make the definitions of each of the terms used in the Safe & SuRe framework and therefore the app clear for the users from the offset.

> *"That's why we have to get the definition bang on otherwise the operator is going to get lost"*

In order to address this concern, earlier versions of the app were edited to include prompts under each of the section headings in the add data section of the app (Figure 6.16). Buttons to navigate to section definitions and examples were also added to each 'Add data' screen (Figure 6.16).

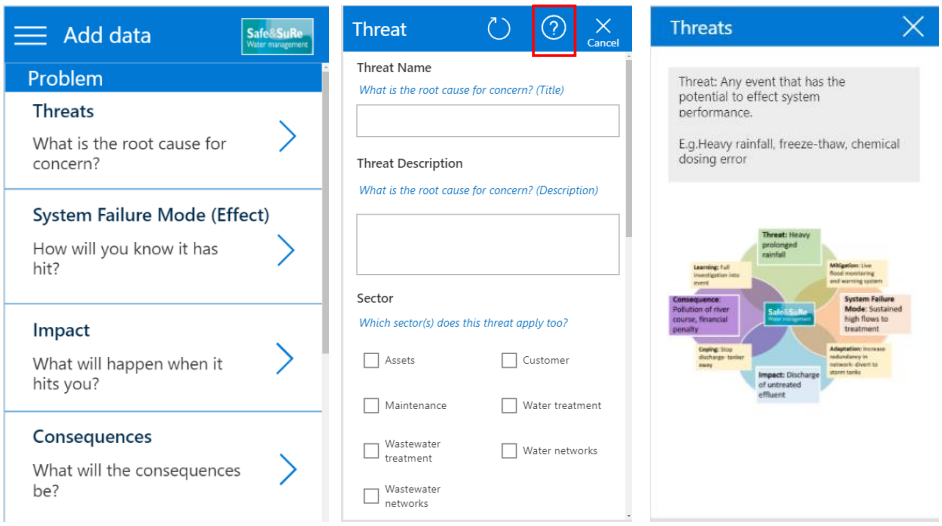

Figure 6.16 Prompts provided under category headings

Discussions had by participants on terminology used with the app and wider framework also touched on how important it was for users to define interventions correctly.

> *"I think that's fine as long as you don't mind if they put that as mitigation instead of, adaptation, because that's where you get really confused"*

Participants generally considered it to be more difficult to differentiate between the four interventions compared with threats, system failure modes, impacts and consequences, and questioned what the ramifications would be if users continued to confuse the categories. Such points of discussion was connected to the level in which the app would be pitched, as well as how the data that was collected by the app would be managed, and who would be responsible for it.

Issues of scale and interconnectivity

One participant highlighted how interrelated issues around definition and terminology were with questions over who the app was designed for and at what level it would be used.

“what I mean is… [an operator might say] that the threat is that the pump is not pumping enough, actually, that is not the threat. The threat, [is that] there's too much flow. But if…you don't do the chain, you're not going to say oh I have too much flow. So, the threats the flow, the effect [system failure mode]…is the pump it can’t cope”

Here the participant is referring to the level of the system that is being analysed or evaluated and was again enquiring how differences in understanding and approach to the definitions and terminology would be understood by the app and its wider management. For example, with regards to the Safe & SuRe framework the term threat is defined as *“any event that has the potential to effect system performance”.* In the example provided by the participant the treatment works operator may consider ‘pump failure’ to be the threat, as this is what has the potential to affect the performance of the treatment works. However, a treatment works manager, whose job it is to oversee the management of multiple treatment works, could instead identify the threat to be the levels of flow within the wider network and failure of one pump to instead be a classified as a system failure mode.

Following multiple rounds of discussion regarding the scale of use and at what level the app should be designed for, participants agreed that the app should be targeted towards the ‘operator level’.

“This is about seeing through the eyes of the operator. And he won’t be thinking about PR 24…etc. So, I think it's about...not having it so broad that becomes a problem for everybody to understand…

So, you would see that as site level and process level, or at asset level?

At operator level I still stick to that same one, you know he or she can define the threat. Everything else at whatever level they see it at.”

The agreement between participants centred around prioritising what the ultimate aim of the app was, which they identified to be gaining additional perspective from the operator level, learning from past experience, and increasing communication.

"[We want] the operators view of what he or she thinks is the root causes without doing a full FMECA (failure mode effects criticality analysis), without community guidelines and all that kind of stuff because that takes time, just that initial thinking"

"The learning from it and the recordings. The increase in the communication of ideas between teams"

The view was that although this may result in occasional contradictions and confusion of categorisation, that once the data had been collected due to the way in which the data is stored in SharePoint, it could be easily re-classified at a later date by those tasked with analysis.

Flow of data and information

Other points of discussion that were covered within the focus groups included how the data would be used once it had been submitted by operators, who would own the data, and who would be responsible for analysis and dissemination of results.

Participants discussed positives and negatives of existing systems and procedures that are in place within NW which the app would differ from.

"[It asks] what's your problem, and then and how are you going to fix it, and how much is it going to cost, you know, how are you going to do it when are you going to do it and you think, you know it's not encouraging people to raise issues because it just creates more work for us."

The system users were discussing was designed to gather information regarding requests for replacement of equipment or investment from operational teams for their sites. The system required users to provide details of what was required and why, as well as full costings, suppliers and possible alternatives. Criticism of this system from users was centred on the amount of time and input that was required from operational teams as well as the need for them to enter information that was outside of their skills set. Participants therefore repeatedly emphasised their desire for the Safe &SuRe app to be designed in a way in which operators were only required to enter their initial views on possible

threats to system performance, failure modes, impacts consequences, and related interventions.

> *“What we're looking for here, and correct me if I'm wrong, we would be quite happy at this stage, to just, identify the threats, and then we can build upon that afterwards.”*

Participants came to the agreement that the app should be designed for operators with team leaders or those with roles designed to support operations taking responsibility for analysing results and further disseminating the resulting information.

Testing the app and dissemination

Participation and the process of co-development of tools for field-workers and operational staff was also discussed within the focus groups, specifically with regards to another operations focussed app that the organisation had just released. Participants emphasised a preference for testing the app in advance of wide scale release and being provided with the opportunity to provide feedback.

> *“The thing is until you get your hands on it and see how it looks…you obviously can't say this is good or this is bad or comment. [We saw] flow diagrams and all sorts…but to actually see it as a user, how it can work…that's what we want.”*

A past negative experience that some users had with the development of field-based technology that they had not been consulted on or involved in the design and development process, emphasised to users the need for them to be involved in the future, if a successful tool or application that operational teams were happy and willing to use was to be developed.

> *“because ultimately you want to want to look [at it] and feel it, [but for us field workers] we didn't really know”*

Such feedback gained from user's links to ideas around user experience and general usability of the tool as previously discussed.

> *"how people react [and] user experience is just as important as the content that we're putting in it, because we won't be able to use it, it might be fantastic, but if people just get bored halfway through and stop using it doesn't achieve the aim, so this bit is the important bit really"*

The view held by many of the participants that were involved in this set of focus groups again highlighted the need for increased use of methods of co-development and the participatory approach.

Not a standalone app

Other sections of the discussion that was had during the focus groups was based around the view that this app was considered to be a 'proof of concept' or working example of how resilience planning and resilience based thought can be built into pre-existing systems that are currently used by field-based workers and operational teams.

> *"is the plan for this to build it into the current Maximo app?"*
> *"This is about as good a proof of concept as you can get to allow a developer to slot it into the Maximo app to actually work out which bits, we take…how do we do the workflows, everything that we're doing here is exactly what I'm doing with [consultants] to say, let's do a real proof of concept, not sketching on a wall."*

Users felt that learnings from this process could be used to inform future developments with regards to resilience based work at the operational level as well as wider processes and methods used for how future technology is developed within the business. However, their view was that operational staff would be more likely to engage in the app and its contents if it was part of an applications that workers are already required to use on a daily basis.

6.6 Discussion

This research has revealed that the Safe & SuRe framework can be used as a basis for the development of an online application and more specifically a mobile app.

Although the initial version of the tool, based in Microsoft Excel VBA worked well, developments in technology during the course of this research project have allowed for the development of an application in a format that is preferred by users. Ease of use and accessibility for users was a central theme that ran throughout the focus groups and co-development phase of the research. The developments within Microsoft Power Apps and the wide scale roll out of Microsoft 365 by NW across the organisation provided the researcher with this option. The use of Power Apps for data collection also ensured that the results would be stored in format that is already in use across the organisation (SharePoint). Although system wide roll out of SharePoint and the wider Microsoft Office 365 applications was planned within the organisation, the outbreak of the COVID-19 pandemic undoubtedly accelerated this process. This alone meant that results could be easily incorporated into other systems and modes of analysis that were already in use within the organisation.

Although feedback from users highlighted that they did not see this tool being used in the future as a ‘standalone’ app, the creation of a proof of concept tool provided users with the opportunity to test out the technology and provide feedback. Co-development and the participatory process was considered to be very important by the users. This experience, combined with past learnings gained from the development of now in use applications within the organisation, helped emphasise to participants the importance of field-workers and operational staff being provided with an opportunity to interact with prototypes and physical products, as well as the ability for them to provide feedback before wide-scale roll out.

The Safe & SuRe framework itself was well received by participants and users of the app as a mode of increasing resilience thought and discussion within operational teams, however issues around terminology and definitions remained. Participants often found it hard to differentiate between mitigation

and adaptation interventions as well as threats and system failure modes. Prompts in the form of simple questions on the ‘Add Data’ section of the app helped simplify the process for some users. However, focus group participants ultimately decided that occasional errors by users with regards to categorisation could be addressed by separating the responsibility for data collection and analysis, with responsibility for data collection lying with operators and field workers, and analysis with team leaders or those with roles related to operations but who are based in offices.

When adding data to the framework users still preferred to start with the identification of a threat, then move to failure modes, impacts and consequences before thinking about interventions separately. The repeated desire for operators to return to threat identification and the use of a top-down approach highlights how engrained the traditional risk-based approach to system management is within the organisation and specifically operational roles. This issue links to wider discussions around resilience understanding and resilience culture within the organisation and the wider water sector.

6.7 Chapter summary

This chapter has presented the results on how a resilience based mobile application can be developed using the Safe & SuRe framework.

In answering the research questions that were posed at the beginning of the chapter in Section 6.1, it was identified that:

- The central aims of the application were identified to be the creation of a tool for operators and field workers to enter initial data on what they perceived to be threats to system performance as well as potential resulting system failure modes, impacts, consequences and interventions.
- Although Microsoft Power Apps was found to be an adequate platform for the development of the app. Feedback from participants highlighted a desire for the app to be incorporated into an existing data collection app currently used by operational teams, rather than as a standalone tool.

- Participants agreed that the tool should be developed for, and tailored too, operational staff and field workers in order to provide further insight at the operational level.
- The research found that results should be stored and displayed in a format that is familiar to the organisation, with responsibility for the analysis of results and dissemination of resulting information placed on a role outside of operations.
- Regular use of the app was considered to have the potential to contribute towards a resilience culture through increased resilience understanding and use of related terminology, increased awareness of system interconnectivity and possible modes of intervention.

Chapter 7: Operationalising resilience in the water sector

7.1 Introduction

Chapter 6 explored how a resilience based mobile application can be developed using the Safe & SuRe framework, this time using Microsoft Power Apps. Results highlighted how the tool itself could be best developed and answered questions around usability and how results could be displayed. However, questions remain around how such a tool could be implemented within an organisation, and how it could contribute towards the development of a resilience culture.

This chapter aims to contribute to the development of policy and practice recommendations to enhance the successful operationalisation of resilience within the organisation. This Chapter addresses Objective 5 which posits the following research questions:

i. What are the current organisational themes that need to be considered in the dissemination of a resilience strategy?
ii. How would a resilience strategy fit with current operational practices?

This chapter uses semi-structured interview questions to investigate the historical approach to resilience taken by NW and the wider sector, and to identify changes required before resilience can be further operationalised.

The remainder of this chapter is structured as follows. Section 7.2 discusses results from the semi-structured interviews that were conducted with operational members of the workforce, which have been presented by theme. Section 7.3 provides a discussion based on the data collected. A chapter summary is then provided in Section 7.4.

7.2 Semi-structured Interviews

As outlined in Chapter 3, Section 3.7.3, ten semi-structured interviews were conducted with members of the NW workforce, via Microsoft Teams. This was to provide further context with regards to how the organisation and sector have historically approached the topic of resilience, and to identify changes that are required within the organisation, before wide scale operationalisation can occur. Participants were suggested by industrial supervisor Ken Black, based on length of time spent working in the water industry or at NW, and understanding of operational processes and procedures. A total of twelve interview questions were developed, and centred on historic and current resilience understanding, current levels of operationalisation and required changes to policy and legislation. Questions on how a resilience based app could be disseminated across the organisation were also included. Interviews were transcribed and analysed in Nvivo. Results from the interviews are presented below by theme.

7.2.1 Historical approach to resilience

Asset centric view

Discussion around the historical approach to resilience both within NW and the wider water sector highlighted the focus on assets and asset management, that has previously existed.

> *"Historically being resilient has mainly focussed on the assets"*
> **Participant 002**

Multiple participants referred to previously carrying out or *"thinking about"* what are now referred to as resilience based activities and actions, prior to the popularisation of the term 'resilience'. However, such actions were again historically focussed on assets, and typically centred around the reliability of physical assets used within water and wastewater operations.

> *"I think we are all thinking about resilience and have been for a long time but maybe didn't call it, resilience…maybe called it asset health, or reliability, or future proofing assets. We probably just called it something else. We have been thinking about it and doing things about it for a long time. Just not under the banner of resilience and maybe not in a structured way."* **Participant 007**

Participants highlighted the previous disjointed approach to system resilience and asset management with a traditional focus on individual assets rather than approaching issues from a wider system level. One participant also referred to a historic focus on asset reliability as it was considered more *"obvious".*

> *"Probably in the past in silos. We looked at resilience really for specific assets. Nearly cherry picking. Sounds probably worse than it is, but …we looked at specific aspects of the business...There's a line between resilience and reliability, I think probably…we came in from the reliability point of view because it was… more obvious."* **Participant 001**

Reference was also made to the concept of business continuity and connections to resilience, as well as the recent interest in the topic of resilience from water sector regulators.

> *"I think it's only recently, as in the past five years that regulators have started to tell us what they think about resilience. I think companies have definitely considered it so I can think back… 15 years or so, longer, even 20 years, where we, as part of our business continuity team, we've had in place incident procedures."* **Participant 007**

Participant's perception of resilience as a term connected to other system, or organisational traits, such as reliability and business continuity relates to the current resilience understanding that exists within both the organisation and wider water sector.

7.2.2 Definition and understanding of resilience at the operational level

Resilience understanding

Answers to questions regarding how individuals understand the term resilience with regards to NW were again centred around assets and the status of equipment required in the treatment of water and wastewater.

> *"So, I'd say resilience for Northumbrian Water. On the whole, again…it's asset resilience. So how long are certain bits of kit going to last, and when they fail what [are we] going to have in place. When they fail, because inevitably they will."* **Participant 002**

> *"Knowing that we've got enough redundancy in our assets or capacity in the network, that if there's a failure anywhere, we still have the capability to supply our customers."* **Participant 003**

With some participants noting the ability to cope as a key aspect of resilience, where others noted response and planning.

> *"I see resilience as our ability to flex and…to cope with anything that gets thrown at us"* **Participant 005**

> *"Maybe what resiliency is, is just an indicator of how well you can cope with a specific selection of risk."* **Participant 001**

> *"It's about understanding and being responsive and reactive and planning for external shocks and stresses."* **Participant 010**

One participant recognised the change in resilience understanding and popularity of the term during recent years, and how this has impacted and related to the water sector.

> *"I guess the understanding of resilience has probably been developing hasn't it across the world if you like across the industry, so I think we've probably been trying to adapt to that as well."* **Participant 010**

Other participants discussed how to them, the concept of resilience 'blurs' with other related terms.

> *"It blurs with sustainable. So, it's you know how you link resilience with sustainability and resilience with reliability. I think reliability is probably short term, sustainability is probably long term, and the resilience is probably something that stretches between those two."* **Participant 001**

Responses to questions on if there is a single consistent definition of the term resilience within the business were mixed. One participant stated that they believed a consistent understanding of the term did exist across the business.

> *"It's not… known that it's written down in terms of the definition, but you know, you will be able to get someone to really understand [and] articulate it consistently across the business."* **Participant 004**

However, others disagreed with this statement and instead believed that individuals within the organisation would define the term *"in their own way"* **Participant 001**.

With regards to whether there ever should be one single definition, again different views existed amongst participants.

> *"We need to have a company view on what is resilience and also probably then derive it into the different areas of the business. What it means for different areas, and then how you aggregate all those sorts of different branches of resilience into your overall resilience."* **Participant 001**

> *"I think there shouldn't be one and I don't think there is"* **Participant 008**

One participant outlined a need for *"everyone within the company"* to understand resilience in line with a central company definition due to wider changing societal expectations.

> *"I think expectations are changing over time so we're now more dependent than ever before on our asset base to live with and continue to deliver those expectations and those services. So that's why I think it's important for everyone in the company, to understand, whatever our personal definition of resilience is, and understand how that purpose, links to that. So that people have a sense of identity, about our organisation"* **Participant 008**

Another concept explored by one participant with regards to resilience understanding was that of the view that although operators within NW may not

talk about or discuss actions using resilience based language, they would be able to identify and discuss resilience based measures that effect the daily running of their sites.

> *"So, it's very simple. If you went and spoke to an operator, talked about resilience and [used] some of the language that comes from outside of NW, they might scratch their head. But in its simplest terms, they will tell you that I've only got one pump in operation, and if my standby is out to be fixed by maintenance… I feel vulnerable. Because if that one breaks, then I'm going to not be able to supply water. They'll be able to tell you."* **Participant 003**

7.2.3 Changes in approach to resilience

Approaching resilience

Another theme that arose from analysis of the semi-structured interviews was that of the changing view and approach to the topic of resilience by the organisation. Specifically, with regards to changes that employees have noticed on an operational and individual site level. One participant highlighted a change in the way investment projects are now funded within the business.

> *"There's a change in the way you're choosing projects I can see…in the last 20 years there's been a shift."* **Participant 001**

Another participant noted a change in regulatory environment to one more focussed on resilience. This is something that they also considered to be mirrored across wider society.

> *"definitely the regulatory environment is moving in that direction. I think you're right, society is moving us in that direction when it comes to resilience, you know, the climate type events that we've had with, heavy rain and flooding, drought, this sort of stuff. And even just the availability agenda as well as this is kind of pushing us to be more resilient in the type of materials that we're going to be using"* **Participant 003**

Although participants had acknowledged a change in approach from the economic regulator Ofwat, one questioned whether tangible actions had followed the changes to Price Review documentation and structure.

> *"in the last Price Review, resilience is a key thing. They seemed to kind of open the door to companies asking for additional investment to be more resilient. But then, in effect, not a lot of resilience schemes actually got…funded. I think…you need to look at the regulatory framework and think about how companies can be incentivised if you like to…continue and to be more resilient in the future. [If it's] going to be in a regime where…any asked for money just gets disallowed then that's not going to… be sustainable."* **Participant 010**

This both highlights and refers to wider issues around the five year regulatory period, and the level of funding required by companies in the UK to invest in more long term measures, that are aimed at increasing the overall resilience of water and wastewater systems.

7.2.4 Required changes to organisational and operational practices

Response vs preparation

Multiple participants noted a need for system management to evolve from a purely response focussed view and approach, to one centred more in preparation and foreplaning. One participant stated that they did not think that the necessary structures were in place to facilitate longer term planning within the organisation, with the focus remaining on the *'here and now'*.

> *"I don't think that we've necessarily got the structures in place to be able to really kind of deal with resilience. We are very much about the here and now rather than thinking about how to improve. And what resilience means in the medium, and the longer term because of course there's a much longer timeframe involved with some of these decisions."* **Participant 003**

Another participant outlined that a change in approach was also required with regards to how members of the workforce were rewarded and how certain

actions were valued. Due to the nature of utility companies and more specifically the water sector, historically actions taken to minimise the impacts and consequences of sudden onset events have been publicly applauded and re-warded within the organisation. However, it is now considered that such an approach has led to the development of an operational workforce that is dependent on *'hero mentality'* and the requirement of constant 'firefighting'.

> *"it is about recognising and rewarding the work we do on long term thinking, rather than just recognising and rewarding the hero mentality. Yeah, we have to do this is at all levels in the organisation, including the executive team, they have to recognise how important this long-term planning is to us...because otherwise we're just stuck in a short-term cycle."* **Participant 006**

> *"We like to congratulate ourselves on our ability to adapt. You know, everyone likes a crisis"* **Participant 005**

This is something that is considered to be having a detrimental impact on a more sustainable approach to operations, with regards to both the physical assets, and wellbeing of the operational workforce. One participant outlined that although the workforce enjoys the need to be constantly reacting to incidents that this approach is not sustainable and that instead, that energy could be directed elsewhere.

> *"Yeah, you want to be the hero… but it's not nice to get called in the middle of the night and get told you are going to run out of water…People enjoy that side of things and that's how it's really exciting and really fun and they're really happy when they solve the problem…Well enough of that, we can't go on. We need to be operating in a steady state without all the drama…We need to direct the energy somewhere else….it's just going to take a lot to actually get there"* **Participant 003**

Although expertise in the ability to react and respond to incidents is undoubtedly a positive trait for an operational workforce to possess, and important for overall system resilience, participants expressed their frustration at the impact a continued focus on reaction is now having across operations. With one participant suggesting that at times the wrong decisions are made due to the requirement to quickly deal with the issue that is there now.

“We're far too reactive and far too short term focused. We don't have longer term resilience or even medium-term resilience built into our investment programmes or operational programmes to be able to make those improvements, because we're reacting and having to stop any of the kind of medium-term stuff at the expense of doing something that's broken now.” **Participant 003**

“That's a real, real frustration because it means we're not really managing the risks, we're reacting and responding…And that also means that you have a knock-on impact on the efficiency of delivering that work, and the ability of actually making the right decisions because we're having to do things so quickly and so reactively that they end up costing more money, [and] taking more time. Possibly you end up spending money on something, you don't need to do because it's a problem now” **Participant 003**

Changes to culture

Conversations around the existence of the ‘hero mentality’ within the organisation’s workforce, and its connections to focus on short term response rather than long term planning are especially important with regards to the development of a resilience culture.

“we have a hero mentality, so…people get congratulated for being firefighters and get a big pat on the back and rewards or things like that. And that was the culture we had created. Actually, what we should be doing is rewarding the people who are thinking about the future, as well. And those are the plans for the future to make sure we are resilient. So, I think, on that basis, it is possible to create a resilience culture. But I don't think we're there yet. I think we still have a short-term view, we are trying to change, we put some new structures in place some new teams in place, but I think change in culture is going to take some time.” **Participant 007**

One participant acknowledged actions that are required before a change in culture, to one focussed on resilience rather than only short-term risk management, can take place. However, it was noted that such a shift within the organisation is going to take some time.

Organisational practices

Other required changes that were outlined by interview participants included a suggestion to re-direct a lot of administrative work back away from operational teams, specifically site managers, for them to spend more time on operational planning activities. One participant highlighted how much of their time is now spent 'chasing people' in other areas of the business. This was considered to be reducing their ability to focus on the long-term planning for their asset base.

> *"My job is chasing people all day every day. And it's often the same people. So, you just think well, actually, I should be looking at water supply in six months' time, or what is it in five years' time?...you just [end up] being bogged down in the day to day…You're just chasing their poor performance, really"* **Participant 009**

Here the participant considered 'poor performance' in other areas of the business to be having a detrimental impact on operations. Such a view highlights the level of interconnectivity that exists within NW and the wider water sector, as well as the level of support that operational teams require to meet regulated levels of performance.

Data governance was another area identified by participants that requires improvement before resilience can be further operationalised within the organisation. One participant expressed concern over the organisations ability to collect data relating to asset performance.

> *"I don't understand the appalling lack of data collection and understanding of what our assets do. Now, if we put in the correct governance, and I'll say, if we put the right governance in, because it hasn't been demonstrated yet around the collection of data…you… should have a good idea of who's got the skill sets to do which particular jobs, and it should move us forward. But I've got some grave doubts."* **Participant 006**

Here it is argued that increased data collection and the correct form of data governance would contribute towards a better understanding of the organisation's asset base and ultimately system performance.

Socio vs technical

Another issue that was highlighted by participants with regards to required changes before resilience can be fully operationalised within the business, was that of the aging asset base.

> *"the argument is that automation is going to solve all our problems and we're not going to need any operators. But in all honesty, we are at least 15 years behind the rest of the industry in terms of the condition of our assets. There's no way that we can automate the vast majority of the sites…you can't just bolt a computer on it and tell it to operate. And actually, I think there's an argument that no one really, wants to hear that it's probably cheaper to employ more people than it is to upgrade all of the sites."* **Participant 003**

This participant outlines the disconnect that exists between plans to automate sites to increase resilience, and the suitability of the assets to such changes. Here it is suggested that in order to more efficiently run the assets it may make more financial sense to hire additional members of staff rather than pay for technology to be fitted to sites that are not compatible. This point also links to conversations around the connections between socio and technical systems that exist within the UK water sector, and a mandate that has typically prioritised the technical aspects of the socio-technical systems rather than the socio (people).

Multiple participants discussed issues relating to how the technical and social aspects of the system are operated in relation to each other, and specifically with regards to the prioritisation of assets and technical systems over the workforce. Here the participant highlights the need for operators to be able to effectively and efficiently operate the assets, again emphasising the connections that exist between the two aspects of the system.

> *"I don't think we ever really looked outside of that, I think we were very much heavily focused on the asset side of things and not the people side of things. Which I think is wrong, because if you don't have the right people, you don't have the right operators, you're not going to get the most out of the assets"* ***Participant*** **002**

Another issue discussed in the semi-structured interviews in relation to the social systems and the organisation's workforce, was that of the replacement

rate of skilled workers due to both retirement rates amongst an ageing workforce, and personnel efficiency measures introduced by the organisation over recent years.

> *"We don't have a great turnover of staff... there's lots of people have retired, who did traditionally work in operations."* **Participant 006**

> *"we've reduced our frontline workforces over the years. And frontline operators and controllers, tend to be quite skilled people, and not very easy to replace. And obviously that's been brought to the fore over the last year... so you know this asset resilience is also people resilience"* **Participant 003**

Participants also discussed the amount of time taken to train a front-line operator to the required standard. This again emphasises that the replacement of skilled operational staff is not an easy or straightforward task and one that the industry has so far fallen behind on.

> *"people resilience is a really big problem that we are going to have because it can take up to a year to be able to get someone fully operational"* **Participant 003**

Here participants referred to the concept of people resilience both with regards to the resilience of social systems as well as individuals themselves.

> *"Yeah, so that emotional kind of resilience for people is a real issue...that we've got to be cognizant of, but I think burnout might be too strong a word for what's happened over the last year. But I'm certainly seeing, through the last three months, that people are kind of fraying around the edges a little bit in terms of how they're feeling and some of the behaviours that are coming out after a year's worth of working in isolation"* **Participant 003**

Participants acknowledged the impact of changes to working practices that had been experienced during the COVID-19 pandemic and the impact that such changes had had on the wellbeing of operations-based staff members.

7.2.5 Dissemination of resilience based app

Responses to questions on implementation of the app were centred around how a new piece of technology could be disseminated within operational teams in NW. Participants provided insight into how existing systems and tools have previously been disseminated within NW. In this example one participant explained how results from a health and safety app used by the NW workforce are included in individual appraisals.

> *"So therefore, when I do all my appraisals with the guys,* [name] *is top of the league, so fantastic well done. Looks like you're doing at least one a day… So, crack on. Conversely, as you can imagine,* [name] *why don't you think it's as important as other members of the team? and* [highlight] *lots of things that may be potentially very damaging to your health and safety. So, if you could do something similar for resilience, then that will be fabulous. I said before, but it comes back to how does it impact the individual"* **Participant 002**

Here the participant outlines how they believe that providing users with examples of how the work impacts them on an individual level is key to encouraging regular use of the tool. By including use of the tool as a target associated with individual appraisals, the participant believes that engagement has increased across operations.

Another participant considered the use of the app as a communication tool to be central to uptake and use by the operational workforce. Here they used the example of a process of analysis and feedback that has been introduced to water operations over recent years.

> *"So, the scorecard for me, it's been a real blessing, because it has now put information in front of people. And we're still in that process of going through that cultural change to convince the person who's running the works that it's important to them…It's all about planning, you know, they talk about that all the time…before this thing happens…this looks like it's starting to happen now, so we [have the opportunity to] go away and plan to stop it from getting any worse…And I guess that that's essentially all the resilience app is trying to do as well, but it's just about helping identify an issue isn't it? And then communicating out so actually this is really*

causing a problem here, we think it's a potential issue, how do we get it somewhere else." **Participant 005**

The 'scorecard' discussed by participants is a set of measures against which data is collected for water operational sites each day. The categories covered are safety, quality, cost, delivery and people. At the start of each day, results and potential trends with regards to performance of the site and the wider network are reported back to the workforce in a morning team briefing. The aim is to provide all members of the site workforce with information so they can operate sites in the best possible way and to track site wide performance trends over time. The inclusion of more than just technical operating data is an effort by the water operations team to approach issues from a system thinking level. Participants highlighted that this method of scorecard data collection and reporting is only in use in the water operations team, and has not been applied within other areas of NW.

With regards to the resilience app and encouraging engagement within the operational workforce, it was considered that marketing the app as a method of communication for operations to record information that they have observed, or suggestions they may have on how to improve, would prove to be key.

7.3 Discussion

Analysis of the semi-structured interviews conducted with members of NW workforce, have identified seven organisational themes (Figure 7.1) that need to be considered prior to the dissemination of a resilience strategy within NW.

Figure 7.1 Seven organisational themes identified in semi-structured interviews.

With regards to how the concept of resilience has historically been approached within NW, respondents highlighted the typical asset centric approach that has been taken. Such a focus on the reliability and 'health' of technical aspects of socio-technical systems as an answer to questions over system resilience, is a theme that can be seen across the wider UK water sector. This approach relates to a traditional risk based view of system management linked to a historical perspective of 'building better' and creating systems that are 'fail safe' (Butler *et al.*, 2014; Makropoulos *et al.*, 2018). In which physical engineered assets and their health are considered to be the priority for achieving and maintaining the required level of system performance. These results correlate with research published by Brown, (2014) which emphasises a tendency for socio-technical systems to focus on disturbances by exogenous forces which often underplay the internal social dynamics of the system in question.

The tendency to overlook making changes or improvements to social systems with regards to improving overall system performance within the water sector, was again highlighted by participants during the semi-structured interviews. The views by Participant 003 and Participant 002 that in some cases it would be more efficient and effective to hire additional members of staff than to increase automation of sites, and the reduction in frontline operational staff over recent years, emphasises this point. Participants views and recollection of their experiences are in line with research published by Woo and Vicente, (2003) in which they outline how the implementation of the 'work to rule' campaigns in socio-technical systems negatively impacts performance as the ability to adapt, which in this case is a reduction in operational workforce numbers, is either

removed or shut down. Although Woo and Vincente, (2003) state that the pressure on such systems to continually 'do more with less' is a result or reflection of wider social requirements, in this specific example it is important to note the context of the UK water sector, and specifically for-profit private companies located in England, and the economic regulation framework in which they operate. Although NW have not witnessed any large scale complex failures in recent history, examples of such failures can be seen in other areas of the UK as well as international water sectors, where attempts to 'optimise' one area of the system, and a failure to acknowledge the interactions between social and technical aspects of the system have resulted in significant damage to public and environmental health (Lawson *et al.*, 2020). Such a continued emphasis on the technical aspects of such complex socio-technical systems re-emphasises the need for a shift in paradigm with regards to the management of water systems in the UK, if the concept of resilience is to be successfully operationalised.

The continued focus of the wider sector and NW on the health of physical assets also relates to how the sector define the term resilience. The current resilience definition used by Ofwat, the sectors economic regulator,

> *"Resilience is the ability to cope with, and recover from disruption, and to anticipate trends and variability in order to maintain service for people and protect the natural environment now and in the future"* (Ofwat, 2015),

more closely aligns with the engineering focussed definition of resilience.

Despite the recommendation from the Task and Finish Group in 2015 (Ofwat, 2015), to implement a sector wide definition, in which they provided examples of when lack of definition have hindered progress, at the time of writing, this is still yet to occur. Results from the semi-structured interviews support findings outlined in (Chapter 4) regarding a resilience definition, and further highlight the lack of unified resilience understanding within NW. Views on whether there should be a unified resilience definition within NW were mixed, with some participants considering it important for employees to understand resilience with regards to the organisation and their roles, however others did not view this as a priority. With regards to operational staff, although they do not use what is

considered academic resilience based and related language, participants considered them to have a good understanding of what resilience is with regards to how their systems operate and perform.

Changes to the approach to resilience that have been taken by sector regulators as well as the organisation themselves, have been recognised by participants. Although changes to legislation have been noted, results from the semi-structured interviews suggest that tangible actions related to resilience based legislation are still yet to occur. This finding again suggests that so far, wide scale operationalisation of resilience is yet to occur in the UK water sector.

Another theme that was highlighted within the interviews was that of response versus preparation, and the need for NW to evolve from a purely response based organisation, to one focussed on long-term planning. Respondents highlighted that over the years the organisation has developed an operational workforce that is dependent on 'hero mentality' and the continual requirement for 'firefighting' and outline the need for a move towards long-term planning within all areas of the business. Such results link to findings outlined in Chapter 5, in which a lack of preparation for the outbreak of the COVID-19 pandemic was highlighted by participants. This relates to other issues highlighted by interview participants such as a repeated lack of investment and low replacement rate of treatment works assets, and a failure to replace highly skilled members of the workforce when they reached retirement age. The need for succession planning and plans to address the issues associated with an ageing workforce have been highlighted across the wide water sector (Water UK, 2021). However, results from this study suggest that so far, measures to mitigate such threats have not been implemented.

Participants also highlighted areas in which additional organisational changes are required, before the dissemination of a resilience strategy can take place. Participant 009 stated that issues in other administrative areas of the organisation are negatively impacting their ability to run operational teams to the best of their ability. The participant also considered these issues to be directly impacting their ability to be carrying out longer term planning for the provision of

water and wastewater services. Here, the need for wide scale systems level thinking is outlined as an example of how poor performance in one area of the organisation can have a direct negative impact on operational performance.

With regards to the implementation of a resilience based app, participants considered use of the app as a method of communication, and the requirement to make it personal to users to be key in the dissemination and user engagement process.

7.4 Chapter summary

This chapter has presented the results on which organisational themes need to be considered in the dissemination of a resilience strategy as well as changes that are required within the organisation to facilitate the development of a resilience culture.

In answering the research questions that were proposed at the beginning of the chapter in Section 7.1 it was identified that:

- In total there are seven broad themes that have been identified for consideration in the dissemination of a resilience strategy. These are asset centric, resilience understanding, approaching resilience, response vs preparation, changes to culture, organisational practices, and socio vs technical.
- Historical approaches to the concept of resilience and related measures which have prioritised assets and the technical engineering sections of systems continue to exist within NW. With social systems still seen as a lesser component.
- A move from a response based organisation to one centred on preparation and fore planning is required before a resilience culture can be developed at all levels within the organisation. At present participants do not believe that the necessary structures are in place to facilitate this move.
- NW do not have a single clear definition of the term ‘resilience’ that is used throughout the organisation, and no clear understanding of the term exists within the organisation’s workforce.

- Participants viewed the requirement to make a resilience based app personal to user's key to dissemination and user engagement.

Chapter 8: Development of a strategic framework for the operationalisation of resilience

8.1 Introduction

The previous chapters have analysed results from each of the data collection activities that have been undertaken and have presented the results in isolation. This chapter will combine results and re-contextualise them in terms of the overall thesis aim outlined in Chapter 1, which is *"to develop a strategic framework for the operationalisation of resilience theory in the UK water sector".*

The key messages from the preceding chapters are listed below in Section 8.2. The strategic framework for the operationalisation of resilience within NW is then provided in Section 8.3, along with an outline of how actions identified will be implemented, and who will hold responsibility. An outline of current progress made within NW with regards to the implementation of suggested actions is then provided in Section 8.4, and a chapter summary is provided in Section 8.5.

8.2 Summary of key messages from previous chapters

8.2.1 Chapter 4

- Results from the pilot study highlighted no single consensus regarding understanding of the term resilience within the NW workforce.
- Participants indicated an appetite for increasing central communication from the organisation regarding resilience and more specifically how it relates to individual roles.
- Results suggested that the workforce perceive the company's strengths to lie in response rather than preparation.

8.2.2 Chapter 5

- The Safe & SuRe framework was found to provide a good framework for the development of a research methodology for analysis of existing levels of resilience in an organisation.
- The UK water sector's response to the COVID-19 pandemic was found to be adequate with only a small number of organisations reporting a reduction in system performance.
- Measures such as industry wide collaboration, experience in incident response, robust IT structures, operational staff with experience in remote working, isolation of operational staff and the use of technology were all found to have contributed towards the UK water sector's ability to respond to the pandemic.
- The COVID-19 pandemic provided the water sector with an example of an acute external threat, and highlighted areas in which additional interventions could be put in place to increase organisational and sector wide resilience.

8.2.3 Chapter 6

- The central aims of the resilience app were identified to be the creation of a tool for operations and field workers to enter initial data on what they perceived to be threats to system performance, as well as potential resulting system failure modes, impacts, consequences and interventions.
- Microsoft Power Apps was found to be an adequate platform for the development of the app. However, feedback from participants found a desire for the app to be incorporated into an existing data collection app currently used by operational teams.
- Participants agreed that the tool should be developed for, and tailored too, operational staff and field workers in order to provide further insight at the operational level.
- The research found that results should be stored and displayed in a format that is familiar to the organisation, with responsibility for the analysis of

results and dissemination of resulting information placed on a role outside of operations.

- Regular use of the app was considered to have the potential to contribute towards a resilience culture through increased resilience understanding and use of related terminology, increased awareness of system interconnectivity and possible modes of intervention.

8.2.4 Chapter 7

- Seven themes were identified for consideration in the development and dissemination of a resilience strategy: asset centric, resilience definition and understanding, approaching resilience, response vs preparation, changes to culture, organisational practices, and socio vs technical .
- The historical approach to resilience that prioritised assets and the technical engineering aspects of systems was found to still exist within NW. Social aspects of the system continue to be seen as a lesser component.
- A move from a response based organisations to one centred on preparation and fore planning is required before a resilience culture can be developed within NW. However, at present participants do not believe that the necessary structures are in place to facilitate such a move.
- There is still no single clear definition of the term ‘resilience’ that exists within, or used throughout NW.
- Participants viewed the requirement to make a resilience based app personal to user’s key to dissemination and user engagement.

8.3 Identification of key areas for strategy of operationalisation

Analysis of the results from Chapters 4-7 has highlighted the following cross-cutting themes that were identified to be central to a strategy for the operationalisation of resilience in the water sector.

- Resilience culture
- Resilience definition and understanding
- Resilience communication

A framework for operationalisation of resilience has been developed from the three cross cutting themes as presented in Figure 8.1. Table 8.1 provides further detail with regards to the implementation of the framework. The strategy itself has been developed specifically for NW, however it is suitable for application in many organisations both within, and outside of the UK water sector.

As the notion of resilience is something that a system does, not something that it has (Hollnagel, 2015), this framework is focussed on creating capacity within an organisation, in this case NW, for the potential for resilient performance. The focus of the framework is on actions that can be taken within the social aspects of the socio-technical system, that can be implemented over a shorter time frame. It is hoped that such changes would lead to further changes to the technical aspects of the systems in question.

The following sections provide further detail on the four areas of the strategic framework, as outlined in Figure 8.1. An outline of how actions identified by the framework will be implemented and by who, is provided in Table 8.1.

8.3.1 Strengthen regulation and policy

As identified in Chapters 2, 4 and 7, there is currently no single definition of the term resilience in use within NW, or the wider water sector of England and Wales. Results from both the questionnaire survey (Chapter 4) and the semi-structured interviews (Chapter 7) have further highlighted this. This is despite recommendations for the sector to outline and adopt a single definition from the resilience Task and Finish Group in 2015 (Ofwat, 2015). The agreement on, and publication of, a single definition within the organisation (NW), would provide members of the workforce with a clearer outline of how the organisation

perceive the term and how the concept further relates to individual's roles and responsibilities. It is recommended that NW adopt the resilience definition outlined by Ofwat:

> *"Resilience is the ability to cope with, and recover from, disruption and anticipate trends and variability in order to maintain services for people and protect the natural environment now and in the future"* (Ofwat, 2017a).

Although this definition does not include specific reference to the wider socio aspect of the water sector, it is considered that application of this definition would allow for further clarification, simplification and unification of the term across the water sector of England and Wales. Further details on plans for education and awareness around the concept of resilience are outlined in Section 8.3.2.

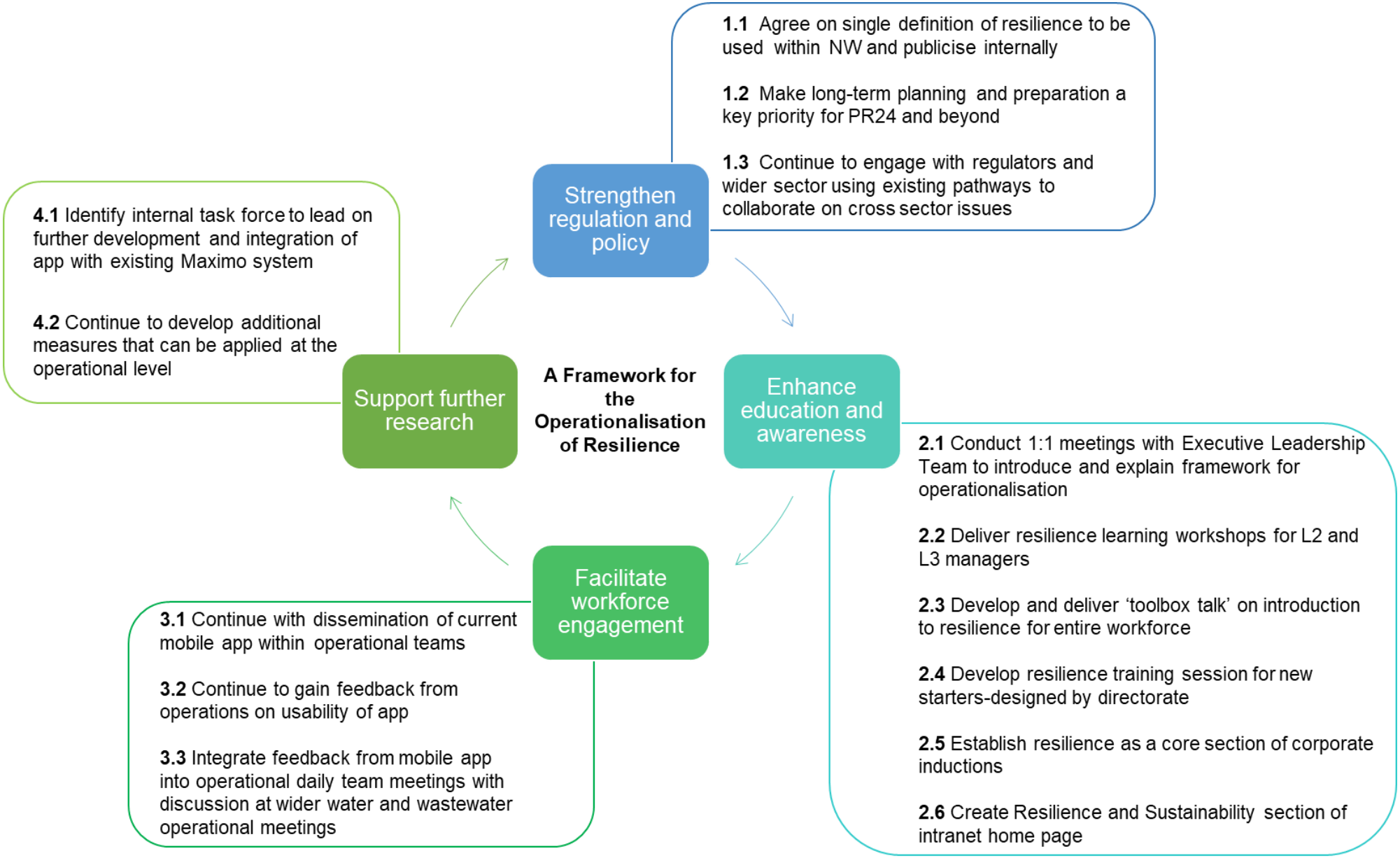

Figure 8.1 Strategic framework for operationalisation of resilience

Table 8.1 Implementation of strategic framework

	Strategy Area	**Action**	**Timeframe (duration of activity)**	**Person/ department responsible**
1.1	Strengthen regulation and policy	Resilience definition	3 months- in place for start of PR24 project	Head of Resilience and Sustainability
1.2		Prioritise response and preparation	1-6 years total. Focus beginning of PR24 process	PR24 Business lead (recruitment underway)
1.3		Cross sector collaboration	2 years	Executive leadership team/ Head of Platinum response
2.1	Enhance education and awareness	Director Meetings	2 months	Head of Resilience and Sustainability
2.2		Resilience workshops	3 months	Head of Resilience and Sustainability
2.3		Resilience toolbox talk	6 months	Head of Resilience and Sustainability
2.4		Corporate Inductions	1 year	Head of Resilience and Sustainability/ People Services
2.5		Team inductions	1 year	Head of Resilience and Sustainability/ People Services
2.6		Resilience and Sustainability Intranet page	3 months	Head of Resilience and Sustainability
3.1	Facilitate workforce engagement	App dissemination	6 months	Head of Resilience and Sustainability
3.2		Usability feedback	1 year	Internal resilience research task force
3.3		Integration of app results	1 year	Head of water operations/ Head of wastewater operations

4.1	Support further research	Creation of internal resilience research task force	1 year	Head of Resilience and Sustainability
4.2		Further development of operational measures	5 years	Internal resilience research task force

Results from Chapters 5 and 7 have highlighted an organisational trait which prioritises response over preparation. In order to move away from a purely reactive based operations environment, further emphasis and priority must be placed on long term planning within the organisation. It is recommended that long-term planning forms a key aspect of NW's planning and preparation for PR24. At the time of writing Ofwat have published their four ambitions for PR24 (Ofwat, 2021) which include:

- Focusing on the long term
- Delivering greater environmental and social value
- Reflecting a clearer understanding of customers and communities
- Driving improvements through efficiency and innovation.

Results highlighted in Chapter 5 outlined the success of the industry working together and collaborating to address issues affecting the sector as a whole. The use of existing strategic level planning and response groups such as the platinum command group set up by Water UK, was considered a success by industry executives that took part in the semi-structured interviews to address Objective 3, and the associated research questions. Participants also emphasised a desire to continue to engage with the wider sector using such mechanisms. Such a combined effort would provide a platform for increased levels of regular communication and collaboration across the industry.

8.3.2 Enhance education and awareness

Results from Chapters 4 and 7 highlighted a lack of consistent knowledge and understanding on the concept of resilience within the NW workforce. An appetite to learn more with regards to how the concept of resilience applies to individual roles, as well as a need for change to start at the director's level was also identified.

One to one meeting with each of the NW directors would provide members of the executive leadership team (ELT), with an in-depth introduction to the wider

plans and requirements for dissemination of resilience based education and awareness methods.

Resilience learning workshops would be designed and delivered to Level 2 (L2) managers (senior managers who directly report to company directors) across the organisation before being further rolled out to Level 3 (L3) managers (report to Level 2). The workshops would be designed to introduce the general concept of resilience and how it relates to what are considered similar concepts (e.g., vulnerability, sustainability, risk, reliability etc.). The sessions would cover how the organisation define the term, how the term relates to sector policy and legislation, and how it relates to individual directorates. Sessions would be interactive with participants required to complete tasks and take part in group discussions.

'Toolbox' talks on what resilience is and how it applies to the organisation would be developed for the rest of the workforce. 'Toolbox' talks are used by the Health and Safety team within NW to communicate new information to the entire workforce. The talks follow a set structure and are designed to fit within monthly team meetings. The talks themselves are either delivered by team leaders, L2 or L3 managers depending on department, team size and schedules. The documentation for the talks come with links to additional materials on the topics, which all members of staff have access to via the intranet homepage. Each talk will have a section that can be customised to the sector or department that it is being delivered too. L2 or L3 managers will be charged with creating the content for the department specific section of the talks following the senior leader resilience workshops.

Additional training materials will be developed for new starters. A basic introduction to the concept of resilience, how the organisation defines the term, and relevance to the water sector will be covered at company corporate inductions. The corporate inductions consist of two half day sessions that every person who starts a new role at NW must complete, independent of role or level of responsibility. Further, more specific training materials will be developed by directorate to be delivered by team leaders for new starters.

A webpage dedicated to ‘Resilience and Sustainability’ will be developed for the NW intranet, with a direct link available on the homepage, where links to further resilience and sustainability resources will be housed. It is hoped that a direct link on the home page and increased exposure of the concept in general, will contribute towards a resilience culture within the organisation.

8.3.3 Facilitate workforce engagement

Dissemination of the current resilience app will continue. Participants involved in the development of the app will continue with their use of the app and recruit further members of their teams for testing. Participants will record feedback on use of the app as well provide feedback at team meetings. The regularity of such meetings will depend on department and directorate. Results from the app will be monitored by area team leaders with feedback provided at wider regional operational meetings.

8.3.4 Support further research

An internal task force will be created to take the lead on exploring the possibility of integrating the app with the existing Maximo system. The group will consist of members of staff who were involved with the development of Maximo, as well as those who participated in the development of this app.

The Head of Resilience and Sustainability will take the lead on continuing to identify and develop measures that can be applied at the operational level to further operationalise resilience.

8.4 Implementation progress

Although NW have not officially adopted the above outlined Framework for Operationalisation of Resilience, individual measures have been taken forward

and implemented by the recently created Resilience and Sustainability team that is led by the Head of Resilience and Sustainability.

Information regarding the progress of implementation of suggested measures is presented by framework theme below. All information provided below is up to date at the time of writing (November 2021).

8.4.1 Strengthen regulation and policy

NW has not yet officially recognised the Ofwat definition of resilience to be how they define the term, however this definition is forming a central role in resilience training and education activities, as outlined in Section 8.4.2.

At the time of writing NW is actively recruiting for PR24 programme leaders. So far, there has been no internal indication from the company to improve long term planning, however the PR24 briefing document published by Ofwat (Ofwat, 2021), would suggest a requirement for WASC's in England and Wales to focus on the long-term for the upcoming regulatory period.

At present, it is unknown to the researcher what mechanisms the industry is using to work together and collaborate.

8.4.2 Enhance education and awareness

The NW Resilience and Sustainability team have so far conducted one–on-one interviews and discussions with members of the ELT, including the CEO.

Resources for resilience workshops for L2 managers have also been delivered (Figure 8.2). Topics that will be covered in the L2 workshops include:

- The need for resilience
- Defining resilience
- Resilience of what? to what? for whom?
- Making the shift to resilience
- Our approach

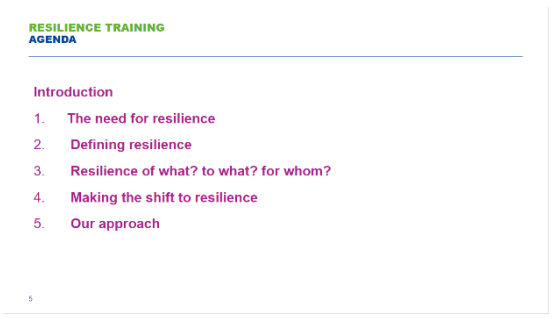

Figure 8.2 Workshop resources for L2 managers

A new company intranet site was developed and launched in 2021. The new site has a section devoted to the Resilience and Sustainability team that is easily accessible from the homepage (Figure 8.3).

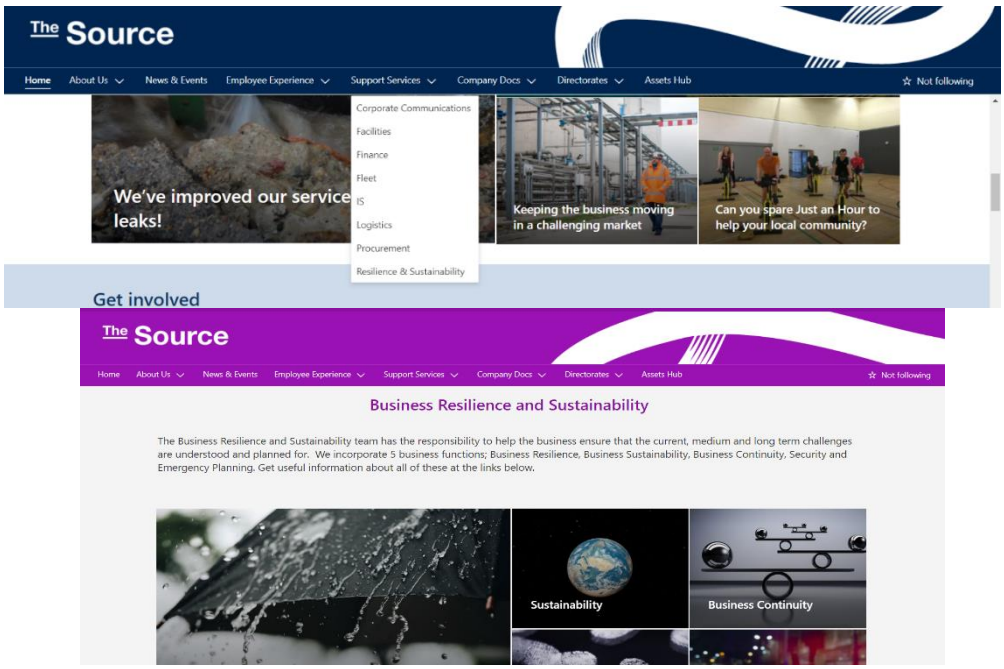

Figure 8.3 Resilience and sustainability section of intranet

8.4.3 Facilitate workforce engagement

When the researcher moved away from being based full time within the organisation, the app was still being used on a trial basis by the individuals that were involved in the development process. It is unknown if results from the app have been further integrated with operational team's processes and procedures.

8.4.4 Support further research

The appointment of an individual to the role of ‘Head of Resilience and Sustainability’ in 2021 has resulted in NW now having an executive level member of staff dedicated to furthering the resilience agenda. Details of this agenda have not yet been made public.

8.5 Chapter summary

This chapter has collated the results from Chapters 4-7 in order to produce a strategic framework for NW, to address the overall aim of the thesis "*to develop a strategic framework for the operationalisation of resilience theory in the UK water sector".*

The framework itself is structured around four key aims:

- Strengthen regulation and policy
- Enhance education and awareness
- Facilitate workforce engagement
- Support further research

Actions have been identified to help achieve each of the four aims with an update provided as to what has so far been achieved within NW.

Chapter 9: Conclusion and Recommendations

9.1 Thesis summary

Increasing levels of uncertainty resulting from a changing climate, rapid population growth and increasing levels of urbanisation, are continuing to pose challenges to the water sector as a whole. Questions over future water supply, delivery, and demand all relate to such uncertainty, with the themes of resilience and sustainability often employed in the response. Within the UK, recent national events, along with changes to legislation and policy, have resulted in the need for the concept of resilience to be developed from an increasingly popularised theoretical concept, into a tangible operational method.

The aim of this research was to develop a strategic framework for the operationalisation of resilience theory within the UK water sector. This was achieved by first exploring how resilience is currently understood across the sector and within a UK based WASC. How an existing resilience based theoretical framework could be used to assess organisational resilience was then investigated, with an example provided through use of a case study based application. A resilience based mobile application was then developed, using co-development methods, for use at the operational level. Finally, policy and practice recommendations were developed in order to aid the operationalisation of resilience.

This chapter provides a summary of the research conducted in order to develop a strategic framework for the operationalisation of resilience in the UK water sector. An initial synthesis of the thesis findings is first presented in Section 9.2 before a more detailed summary of the findings in relation to each objective is provided. Section 9.3 provides some methodological reflections with Section 9.4 providing reflections on the use of the Safe & SuRe framework. Section 9.5 highlights some contributions to the literature with Section 9.6 outlining recommendations for both NW and the wider water sector. Finally suggestions for future research are provided in Section 9.7.

9.2 Research Findings

This research project has found that there remains a clear sense of confusion around the term ‘resilience’ both within, and across, the UK water sector. A single clear definition of resilience remains a requirement if the term is to be fully operationalised. The Safe & SuRe resilience framework was found to be a suitable framework for the development of a research methodology to assess organisational resilience in the UK water sector from a desk based perspective. This is as the framework helped to clearly identify actions that had aided system performance as well as areas in which further interventions could be put in place. The research has also highlighted how a mobile based application can be developed to help further the operationalisation of the resilience concept through a process of co-development. This also highlighted the requirement to involve users in the development of new technology or software at each stage of the development process. Finally seven key organisational themes, (asset centric, resilience understanding, approaching resilience, response vs. preparation, changes to culture, organisational practices and socio vs. technical), that would be required in the dissemination of a resilience strategy were identified.

The findings of this research in relation to each of the outlined objectives are discussed below in further detail.

9.2.1 Objective 1: To explore the current status of resilience in the UK water sector

Objective 2: To understand the concept of resilience within the context of the UK water sector

Recent and reactive changes to policy and legislation in the UK water sector have resulted in the introduction of the resilience concept to WASCs across the UK. The placement of a resilience duty on Ofwat, in the Water Act 2014, to further its resilience objective within the water sector, resulted in organisations

legally required to implement resilience based measures within operations. However, a clear idea of what this meant or entailed was not provided by sector regulators, with many WASCs struggling to understand related requirements. A review of both academic and grey literature has highlighted continued confusion around what the term resilience means, and how related measures can be implemented within the UK water sector.

Definitions of the term resilience for the water sector tend to align with the engineering centred definition and approach, with little consideration given to the social aspect of the systems in question. Failure of sector regulators to outline a clear definition of the term and how it should be perceived and understood, has further contributed to levels of confusion and ambiguity. Results from a questionnaire survey highlighted a lack of consistent understanding of the term within the workforce of one WASC, and a desire for organisations to provide additional communication to their workforce on what the term means and how it applies to individual roles. Although resilience formed one of four central themes to the most recent PR process (PR19), the sector is still considered to be focussed on short term reactive measures rather than long term preparation.

A review of the wider literature identified that a focus on the definition of resilience, with regards to background theory and approach, and the continued development of metrics in an attempt to measure if resilience is present or absent, have continued to cloud the literature and provide barriers to operationalisation. This along with the understanding that many decision-makers consider the content of existing resilience frameworks to be too abstract and far from daily activity, has resulted in poor levels of operationalisation of resilience across the UK water sector

9.2.2 Objective 3: Investigate how an existing resilience framework can be used to assess organisational resilience within the UK water sector

The Safe & SuRe framework was selected for this research project due to the involvement of the wider water sector in its development. The framework provides a theoretical outline of the relationship between threats and their consequences as well as the potential for identification of measures designed to reduce the impacts and consequences of such threats. The framework was used to develop a methodology to assess the operational response of the UK water sector to the COVID-19 pandemic. Use of the frameworks four phases of intervention to structure interview questions and analysis provided a clear outline of how organisations responded to the pandemic, as well as an indication of the organisation's current levels of resilience. Results from the analysis found that the UK water sectors response to the initial phase of the COVID-19 pandemic was adequate with only a small number of organisations reporting a reduction in performance. Measures such as industry wide collaboration, previous experience in incident response and the use of technology were all found to have contributed towards the sector's ability to respond to the pandemic. Use of the Safe & SuRe framework for analysis highlighted areas in which additional interventions could be put in place to increase individual organisation and sector wide resilience.

9.2.3 Objective 4: To develop a resilience based application for use in the UK water sector

This thesis has demonstrated how a resilience based mobile app can be developed to aid the operationalisation of the resilience concept. The app itself was developed through a process of co-development with members of the NW workforce using a series of focus groups and semi-structured interviews. A mobile app that was compatible for use on a mobile phone, tablet and desktop computer was the preferred format for the tool. This was so that multiple people could access and edit the data at once, whilst in the field. Participants identified the central aims of the application to be the creation of a tool for operators and field workers to enter initial data on what they perceived to be the threats to system performance as well as potential resulting system failure modes, impacts, consequences and interventions. Microsoft Power Apps was found to be an adequate platform for the development of the app; however, participants

highlighted a desire for the app to be incorporated into an existing operational data collection tool. Results from focus groups found that the tool should be developed for and tailored to operational staff and field workers as well as to provide the organisation with insight at the operational level. Results from the tool itself should be stored and displayed in a format that is familiar to the organisation in order to encourage further use and incorporation. It was considered that regular use of the tool, alongside additional cross-organisational resilience based learning programmes, would contribute to an increase in both understanding and use of resilience related terminology and ultimately the development of resilience culture.

9.2.4 Objective 5: To develop policy and practice recommendations to enhance the successful operationalisation of resilience within the UK water sector

Results from semi-structured interviews that were conducted with water sector employees, were used to investigate organisational themes that would need to be considered in the dissemination of a resilience strategy. As well as changes required within the organisation to facilitate the development of a resilience culture. Seven broad themes were identified for consideration in the dissemination of a resilience strategy. The seven themes were asset centric, resilience understanding, approaching resilience, response vs. preparation, changes to culture, organisational practices and socio vs technical. Historical approaches to resilience and related measures were found to have prioritised assets and technical engineering sections of systems, as the social aspects were considered a lesser component. A move away from a response based form of operational management, to one centred on preparation and foreplaning, is required before a resilience culture can be developed at all levels of NW as well as the wider water sector. The lack of clear understanding of the term resilience within the NW workforce again emphasised the need for a clear sector wide resilience definition. The need to make technology and new resilience based processes personal to the user was also considered key to the successful dissemination of operationalisation measures.

9.3 Methodological reflections

This thesis has applied a mixed methods approach in order to address the research aims and associated objectives. This approach allowed the researcher to utilise semi-structured interview and focus group methods whilst based within the organisation. The opportunity to be based within an organisation, and witness and contribute to internal business processes and procedures, was one provided by the structure of the STREAM EngD programme. The use of both semi-structured interviews and focus groups within this setting enabled the collection of a very rich data set. The industrial placement enabled the researcher to build relationships with the NW workforce across a time period of multiple years. It is through such connections that participants for semi-structured interviews and focus groups were acquired. The internal organisational position of the industrial supervisor Ken Black, also contributed towards the quality of the participants from operational teams. It is unknown if the same quality of data would have been obtained if it were not for the time and effort that was taken by the researcher and industrial supervisor to build such connections.

9.4 Use of the Safe & SuRe framework

The research has adopted the Safe & SuRe approach to urban water management (Butler *et al.*, 2014) and has applied the Safe &SuRe theoretical framework (Butler *et al.*, 2016). The framework was chosen for use in this research project as it was specifically developed with and for the water sector. The framework was well suited to analysis carried out in order to answer Objective 3: Investigate how an existing resilience framework can be used to assess organisational resilience within the UK water sector. This was as the framework was applied for analysis by researchers who had become familiar with the associated terms and methods of application. Use by a small research team at the desk-based level, ensured everyone understood how the terms used in the framework are defined and to be applied.

Application of the framework in relation to Objective 4: To develop a resilience based application for use in the UK water sector, and Objective 5: To develop policy and practice recommendations to enhance the successful operationalisation of resilience within the UK, found the Safe & SuRe framework to be less well suited. This was mainly due to terminology used within the framework. Members of the NW workforce repeatedly struggled to differentiate between the terms ‘mitigation’ and ‘adaptation’, despite the provision of learning and user guidance materials before and after use of the app. This often resulted in confusion on behalf of the users when using the application that was based on the framework. This highlighted that the Safe & SuRe framework was less well suited to use in the field by a wide range of users.

It is suggested that changes to some of the academic focussed terminology used in the Safe & SuRe framework would improve the suitability of the framework to use in operational environments. Additional materials developed by the Safe & SuRe team on how to further communicate the framework to users with a range of abilities would also benefit the operationalisation process. Provision of further examples of how the framework can be applied to a range of systems, specifically social systems with a focus on workforces, would also help to enhance the framework. Such recommendations would further the framework’s suitability for application in the water sector.

9.5 Contributions to resilience literatures

It is hoped that results from this research will be of use to both policy makers and implementers, as well as contributing to wider academic resilience literature. This thesis has highlighted the suitability of a mixed-methods research methodology for investigating highly complex socio-technical systems. Findings from this research have further highlighted the levels of connectivity between socio and technical systems found within operational systems and environments. Results from the focus groups and semi-structured interviews emphasise how although operational workforce members are aware of such connections and the levels of dependency for required performance, this is

usually overlooked by those who are involved in the building of wider organisational strategy. A lack of clear communication pathways from the bottom up have resulted in such issues persisting. The results also highlight an acknowledgement and need for tacit knowledge in leadership roles within the water industry as a whole. Changes to the make-up of the operational workforce, with regards to retirements and reduced rates of recruitment, are considered to have eroded the resilience of the overall system as critical knowledge and skills sets are lost. This again contributes to the current resilience based literature through highlighting the requirement for investment in social systems in tandem with technical, if overall system resilience is to be improved. Findings highlight the need for understanding with regards to social practices and public behaviours and how they interact and impact the operation of water and wastewater treatment systems. This further reinforces the need for a change in resilience paradigm, and for the water sector to consider all social, technical, and environmental factors and contributors if levels of resilience are ever going to be improved.

9.6 Recommendations

9.6.1 Recommendations for the UK water sector

Based on the results of this thesis, along with previous advisory group recommendations (Ofwat, 2015), it is suggested that Ofwat announce a definition of the term resilience which all companies must adopt, prior to the beginning of the PR24 process. This would create a sense of clarity across the water sector with regards to how the concept of resilience should be defined and interpreted by individual organisations. In turn, this should contribute towards a more succinct understanding that can be communicated to both the internal sector workforce and external stakeholders.

It is recommended that the sector continues to take steps towards a longer-term view with regards to sector planning and operation and move away from a purely response focussed view. Prioritisation of a longer-term approach in the

upcoming PR24 guidance and submissions would aid such a change in approach. A clear focus on investment for the future in PR24 planning and funding awards would help further the messaging to customers, that the sector is committed to increasing resilience and the ability for water and wastewater systems to maintain performance independent of operating scenario. It is also recommended that care is taken to make sure that sector wide strategic planning processes used by separate sector regulators do not contradict or confuse aims and objectives, and instead work together to complement one another. Greater collaboration between regulators with regards to planning procedures and the acknowledgement of system interdependencies would improve results for both society and the environment. It is therefore recommended that future changes to sector policy and legislation should be approached from a system thinking viewpoint.

Results from this research have provided examples of how overall system performance, and therefore resilience, can be improved through changes made to the socio aspect of socio-technical systems. It is recommended that the industry moves away from a focus on the engineered aspects of the system and that moving forward, social systems are considered in conjunction with physical engineered systems, as well as acknowledgement of the interaction between the two.

9.6.2 Recommendations for NW

It is recommended that NW officially adopts the Ofwat resilience definition. This would provide members of the workforce with a clear outline of how the organisation perceive the term as well as how the concept further relates to individuals' roles and responsibilities. Adoption of this would also set the organisation in line with the rest of the industry with regards to understanding of the term resilience.

Further recommendations for NW include the implementation of resilience education programme as outlined in Chapter 8. This would include education sessions for L2 and L3 managers as well as the development of toolbox talks and training programmes for all new starters. It is hoped that such organisation wide training programmes would contribute to the further development of a resilience culture within NW.

Results from this research have shown a historical focus on the ability for the organisation, and more specifically operational teams to develop and focus on skills based response, rather than preparation. It is recommended that NW continues to move towards an approach centred on planning and preparation, including a move towards internally highlighting and rewarding good examples of preparation and long term planning alongside response efforts. It is again considered that such small changes to organisational practices will help shift internal thinking regarding the concept of resilience and the development of a resilience culture.

It is recommended that the organisation create an internal resilience task force to work alongside the Head of Resilience and Sustainability to further implement the strategy outlined in Chapter 8 and the above recommendations. The task force would also be responsible for the further development and implementation of the resilience app outlined in Chapter 6.

9.7 Future research

Following on from this study, there are several areas that could be further developed through continued research. These include a sector wide survey on resilience understanding, similar to the one carried out in the pilot study for the project, as well as the continued development of a resilience based mobile app for use at the operational level. Research into the interdependencies that exist within and across the UK water sector, with specific focus on other utilities would provide further information on where current weaknesses exist, specifically with regards to the occurrence of additional acute external events.

Research into the existing governance structures of the UK water sector and analysis on where and when it would be most effective for resilience based interventions to be put in place at a national level would also further contribute towards the operationalisation of resilience in the UK water sector. Further details are provided in the following sections.

9.7.1 Launch of a sector wide resilience survey

Although best practice guidelines were applied within this study in order to gain a representative sample, the results are limited by both the size of the sample, and the focus on one organisation. A sector wide survey would provide further insight into the understanding of the concept of resilience across the water sector workforce. A wider, more inclusive survey which yields similar results to the one in question, would prove useful with regards to validating the current research findings for future decision making, as well as providing a wider, more diverse set of results.

9.7.2 Further development of mobile app

Following on from the research conducted for this project, the further development of the mobile app based on participant suggestions would provide users with a higher level of integration with existing systems and procedures. In turn it is hoped that such developments would further increase uptake of the tool from operational staff. Such development would also provide the opportunity for additional features to be incorporated into the app.

9.7.3 Sector and utility interdependencies

Further research into the interdependencies that exist between UK water sector stakeholders, as well as between other utilities could provide further insight into vulnerabilities with regards to maintenance of supply in the case of external acute threats. Analysis of the COVID-19 pandemic and impact on the UK water

sector highlighted the impact of an external acute threat on the sector. Additional research could provide organisations with more of an insight into future required mitigation, adaptation and coping measures in the case of another event of similar scale.

9.7.4 Analysis of governance structures and context

Research into existing governance structures within the UK water sector would provide additional information regarding how sector wide resilience based interventions could be implemented nationwide. The complexity of the multiple sectors, stakeholders and different operating structures has at times been cited as barriers for more unified approaches to resilience related issues. Research based on mapping the sector across the four devolved nations (England, Wales, Scotland, Northern Ireland) would provide additional knowledge on how resilience based measures could be implemented in a more unified approach.

Appendix A

Name
Position, Organisation
Via email.

Date:

Dear Name,

I am writing to invite you to take part in some research that we are undertaking together with a team from the University of Exeter and University College Dublin concerning the impacts of the Covid-19 pandemic on the UK water industry.

We have already engaged extensively with water and environmental management professionals in a survey which generated over 500 responses concerning how professionals and their employer organisations had responded to the pandemic, their preparedness and the impacts on their jobs and working practice. The findings are being submitted to CIWEM's peer reviewed Water and Environment Journal shortly.

We would like to build on the findings of this research by undertaking more detailed structured interviews with individuals within all water companies who were closely involved with their operational response. We would be very grateful if either you, or an appropriate colleague, might be able to participate.

If you would be willing to do so, please would you contact XXX XXXX (……) or Elizabeth Lawson (el403@exeter.ac.uk) to arrange an interview.

In the meantime, you may be interested in some of the preliminary findings of the research:

- Unsurprisingly the most frequently reported impact related to changes in working practice to home working, with attendant IT challenges.
- Despite this adjustment, a very large majority of respondents were able to continue their day to day role and continue working effectively, illustrating good resilience borne of strong incident management procedures.

- There have been significant impacts on demand and distribution trends as a result of changing working practice, daytime home occupancy etc, which are likely to endure at least in part as lockdown is eased, and which may impact on the cost burden to companies.
- Climate change and the environment have become greater priorities in terms of focus around which recovery from the pandemic should be built, according to water sector employees.

In addition to follow-on research, we are planning a series of webinars in the autumn to share and discuss findings, together with a programme of public and decision-maker engagement around potential policy and regulation implications of these events. We would of course be pleased to discuss with you how we could reflect your particular experiences and concerns within this work.

I very much hope this is something you might be willing to participate in and we look forward to hearing from you.

Your sincerely,

Terry Fuller

Chief Executive

Appendix B

Participant Information Form

Date: **Participant Number:**

Coronavirus and the Water Sector: Understanding the New Normal

Background: Dr Peter Melville-Shreeve (University of Exeter PI) and Dr Sarah Cotterill (University College Dublin CI) are working in collaboration with CIWEM's Director of Policy Alastair Chisholm to create a Hub/e-Melting Pot for resources (on CIWEM's website) and up to date information relating to impacts associated with the Coronavirus (in the Water Sector).

You are invited to participate in an interview as part of a research project on resilience in the water industry. This is a research project being conducted by CIWEM (full details at foot of document). In order to swiftly process and share findings of the research, CIWEM will be processing the data with support from academic partners from the University of Exeter under a data sharing agreement. Dr Peter Melville-Shreeve can be contacted on pm391@ex.ac.uk should you have any concerns regarding the data management. Elizabeth Lawson, an Engineering Doctoral student on the STREAM IDC programme at the University of Exeter will be conducting the data gathering and processing phase of the project on behalf of CIWEM, who are coordinating the project.

The initial phase of the project has seen over 500 responses from water industry professionals to a CIWEM survey. The research team are processing these stage one findings for dissemination in late summer 2020.

Organisation details: CIWEM SERVICES LIMITED (company registration number 03166701) whose registered address is at 106-109 Saffron Hill, London, EC1N 8QS AND UNIVERSITY OF EXETER whose administrative offices are at Northcote House, The Queen's Drive, Exeter EX4 4QJ

Purpose of Research Phase Two of the project will involve an in depth study of the operational resilience of UK Water Service Providers. The data collected will primarily be used for the development of industry facing outputs and a journal paper. Work will also be written up as a part of a longer term thesis (Elizabeth Lawson). Outputs could include conference presentations, reports and journal articles, and will be available to inform water industry professionals of the challenges faced to date.

Participation: Your participation in this interview is completely voluntary. Nonparticipation will not affect an individual's rights in any way. You will receive no direct benefits from participating in this research study. If you do not wish to answer any specific questions or make further comment you are free to decline.

Taking part: An audio recording of this interview will be made using the record function on Microsoft Teams as well as a Dictaphone for back up purposes. The interview will then be transcribed with all extracts from the discussions conducted being anonymised in order to make sure that no respondent will be personally identifiable. Any reference to specific individuals or identifying qualities will be redacted from the transcripts. No data collected from the interviews will be used for purposes other than those stated above.

How will my information be kept confidential?

The University of Exeter processes personal data for the purposes of carrying out research in the public interest. The University will endeavour to be transparent about its processing of your personal data and this information sheet should provide a clear explanation of this. If you do have any queries about the University's processing of your personal data that cannot be resolved by the research team, further information may be obtained from the University's Data Protection Officer by emailing dataprotection@exeter.ac.uk or at www.exeter.ac.uk/dataprotection

Data Protection: The information you provide will be used for research purposes and will be retained for a period of five years. Personal data and audio recordings of the interviews will be securely stored by CIWEM and the University of Exeter and will be deleted at the end of the project- estimated completion date 1st October 2021. Your personal data will be treated in the strictest confidence and will not be disclosed to any unauthorised third parties. Transcripts from the interviews and analysis of the data collected will be stored on encrypted CIWEM / university owned computers and servers. The results of the research will be published in anonymised form and no participant will be individually identifiable.

What will happen if I don't want to carry on with the study? Participants can ask to stop taking part any anytime without giving a reason. We will remove and destroy any data relating to your involvement and confirm via email that this has been completed within 14 days of your request.

Who has reviewed this study?

This study has been reviewed by the Engineering Team of the University of Exeter's Research Ethics Committee. The findings will be published in an industry journal and shared at webinars or industry conferences.

Contact Details: For further information about the research process, please contact:

Name: Peter Melville-Shreeve on pm391@ex.ac.uk
Postal Address: Centre for Water Systems, Harrison Building, University of Exeter, EX4 4QF.

If you have concerns/questions about the research you would like to discuss with someone else at the University, please contact:

Name: Prof. David Butler
Position: Head of Engineering
Email: d.butler@exeter.ac.uk

Participant Consent Form

Participant Number:

Thank you for reading the information sheet about the study. If you are happy to participate, please complete and sign the form below. Please **select** the boxes below to confirm that you agree with each statement:

I confirm that I have read and understood the information sheet appended to this form dated **xx.xx.xx** and have had the opportunity to ask any questions I have.	
I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without my legal rights being affected.	
I understand that relevant sections of the data collected during the study may be looked at by members of the research team, including individuals from the University of Exeter, University College Dublin and CIWEM where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records.	
I understand that my anonymised data will be kept for a period of up to five years and agree that during this period the data may be used for future research purposes related to this study after the completion of this project.	
I understand that my personal data will be stored on CIWEM and University of Exeter property and servers and will be deleted at the end of the project.	
I agree to take part in this project.	

Name of Participant:	Date:	E-Signature (e.g. JPG)
Name of Researcher:	Date:	Signature:

Appendix C

Participant Information Sheet- Focus Group

Date: Participant Number:

You are invited to participate in a focus group as part of a research project on resilience in the water industry. This is a research project being conducted by Elizabeth Lawson, an EngD student on the STREAM IDC programme at the University of Exeter.

Title of the Research Project: Rooting Out Resilience

Details of the Project: The project aims to undertake a detailed, in depth study of the resilience of Northumbrian Water and the services it provides.

The aim of the project is to further explore the notion of 'resilience' in the context of the water sector of England and Wales, to create a method of assessing the resilience of a water company and its systems, and to identify possible interventions. In order to achieve the aim the research will be split into the development of a resilience based user decision tool which will be developed in collaboration with the water company staff members, as well as the identification of a possible method for dissemination and use within a large organisation. It is hoped that this research will not only help address the gap in methods for resilience assessment in the water industry and lead to successful implementation of a tool within an organisation, but also more broadly contribute to discussions around the operationalisation and implementation of an academic theoretical concept in a complex system.

The data collected will primarily be used for the completion of an EngD thesis, academic research which could include conference presentations, reports and journal articles, and to inform future work on resilience at Northumbrian Water.

Participation: Your participation in this focus group is completely voluntary. Nonparticipation will not affect an individual's rights in any way. You will receive no direct benefits from participating in this research study. If you do not wish to answer any specific questions or take part in a specific part of the discussion you are free to decline. By agreeing to participate in this research you will be contributing to a wider body of knowledge on the use of resilience assessment methods in large organisations. It is possible that results from this study will help influence a change in practices and methods of work in your organisation.

Confidentiality: An audio recording of this focus group will be made using a Dictaphone. The recording will then be transcribed with all extracts from the discussions conducted being anonymised in order to make sure that no respondent will be personally identifiable. Any reference to specific individuals or identifying qualities will be redacted from the transcripts. No data collected from the focus groups will be used for purposes other than those stated above.

Data Protection: The information you provide will be used for research purposes and your personal data will be processed in accordance with current data protection legislation and the University's notification lodged at the Information Commissioner's Office. The research data collected will be retained for a period of five years. Personal data and audio recordings of the interviews will be securely stored on NWL property in a locked cabinet and on NWL servers and will be deleted at the end of the project- estimated complete date 1st October 2021. Your personal data will be treat in the strictest confidence and will not be disclosed to any unauthorised third parties. Transcripts from the focus groups and analysis of the data collected will be stored on encrypted university owned computers and servers. The results of the research will be published in anonymised form and no participant will be individually identifiable.

Contact Details: For further information about the research process, please contact:

Name: Elizabeth Lawson
Postal Address: Centre for Water Systems, Harrison Building, University of Exeter, EX4 4QF.
Email: el403@exeter.ac.uk

If you have concerns/questions about the research you would like to discuss with someone else at the University, please contact:

Name: Professor David Butler
Position: Academic supervisor
Email: d.butler@exeter.ac.uk

Participant Consent Form- Focus Group

Participant Number:

Thank you for reading the information sheet about the study. If you are happy to participate, please complete and sign the form below. Please **tick** the boxes below to confirm that you agree with each statement:

I confirm that I have read and understood the information sheet dated_____/_____/_____and have had the opportunity to ask any questions I have.	☐
I understand that my participation is voluntary, and that nonparticipation would not result in any negative consequences. If I do not wish to answer any particular question or questions or take part in any discussions, I am free to decline.	☐
I understand that my responses will be kept strictly confidential. I understand that I will not be identified or be identifiable in any reports or work that result from the research.	☐
I understand that my anonymised data will be kept for a period of five years and agree that during this period the data may be used for future research purposes related to this study after the completion of this project.	☐
I understand that my personal data will be stored on NWL property and servers and will be deleted at the end of the project.	☐
I agree to take part in this focus group.	☐

Name of Participant:	Date:	Signature:
Name of Researcher:	Date:	Signature:

Appendix D

Participant Information Sheet- Focus Group

Date: Participant Number:

You are invited to participate in a focus group as part of a research project on resilience in the water industry. This is a research project being conducted by Elizabeth Lawson, an EngD student on the STREAM IDC programme at the University of Exeter.

Title of the Research Project: Rooting Out Resilience

Details of the Project: The project aims to undertake a detailed, in depth study of the resilience of Northumbrian Water and the services it provides.

The aim of the project is to further explore the notion of 'resilience' in the context of the water sector of England and Wales, to create a method of assessing the resilience of a water company and its systems, and to identify possible interventions. In order to achieve the aim the research will be split into the development of a resilience based user decision application which will be developed in collaboration with the water company staff members, as well as the identification of a possible method for dissemination and use within a large organisation. It is hoped that this research will not only help address the gap in methods for resilience assessment in the water industry and lead to successful implementation of a tool within an organisation, but also more broadly contribute to discussions around the operationalisation and implementation of an academic theoretical concept in a complex system.

The data collected will primarily be used for the completion of an EngD thesis, academic research which could include conference presentations, reports and journal articles, and to inform future work on resilience at Northumbrian Water.

Participation: Your participation in this focus group is completely voluntary. Nonparticipation will not affect an individual's rights in any way. You will receive no direct benefits from participating in this research study. If you do not wish to answer any specific questions or take part in a specific part of the discussion you are free to decline. By agreeing to participate in this research you will be contributing to a wider body of knowledge on the use of resilience assessment methods in large organisations. It is possible that results from this study will help influence a change in practices and methods of work in your organisation. This focus group will be conducted via the organisations Microsoft Teams account.

Confidentiality: A recording of this focus group will be made using the 'record' function in Microsoft Teams as well as by Dictaphone for back up purposes. The recording will then be transcribed with all extracts from the discussions conducted being anonymised in order to make sure that no respondent will be personally identifiable. Any reference to specific individuals or identifying qualities will be redacted from the transcripts. No

data collected from the focus groups will be used for purposes other than those stated above.

Data Protection: The information you provide will be used for research purposes and your personal data will be processed in accordance with current data protection legislation, and the University's notification lodged at the Information Commissioner's Office. The research data collected will be retained for a period of five years. Personal data and recordings of the interviews will be securely stored on NWL servers and will be deleted at the end of the project- estimated complete date 1st October 2021. Your personal data will be tret in the strictest confidence and will not be disclosed to any unauthorised third parties. Transcripts from the focus groups and analysis of the data collected will be stored on encrypted university owned computers and servers. The results of the research will be published in anonymised form and no participant will be individually identifiable.

Contact Details: For further information about the research process, please contact:

Name: Elizabeth Lawson
Email: el403@exeter.ac.uk or elizabeth.lawson@nwl.co.uk

If you have concerns/questions about the research you would like to discuss with someone else at the University, please contact:

Name: Professor David Butler
Position: Academic supervisor
Email: d.butler@exeter.ac.uk

If you wish to discuss the research further with a member for staff from within NWG, please contact:
Name: Ken Black
Position: Industrial Supervisor
Email: ……

Participant Information Sheet- Focus Group

Participant Number:

Thank you for reading the information sheet about the study. If you are happy to participate, please complete and sign the form below. Please mark the boxes below to confirm that you agree with each statement:

I confirm that I have read and understood the information sheet dated **xx/xx/xx** and have had the opportunity to ask any questions I have.	☐
I understand that my participation is voluntary, and that nonparticipation would not result in any negative consequences. If I do not wish to answer any particular question or questions or take part in any discussions, I am free to decline.	☐
I understand that my responses will be kept strictly confidential. I understand that I will not be identified or be identifiable in any reports or work that result from the research.	☐
I understand that my anonymised data will be kept for a period of five years and agree that during this period the data may be used for future research purposes related to this study after the completion of this project.	☐
I understand that my personal data will be stored on NWL property and servers and will be deleted at the end of the project.	☐
I agree to take part in this focus group.	☐

Name of Participant:	Date:	Signature:
Name of Researcher:	Date:	Signature:

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