ANTICIPATE, REACT, RECOVER

Technical annex: Case studies and good practice for resilience

NATIONAL INFRASTRUCTURE COMMISSION

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Contents

Summary

In developing the evidence base for **Anticipate, React, Recover: Resilient infrastructure systems**, the final report of the Resilience Study, the Commission reviewed UK and international case studies related to the resilience of infrastructure systems. A selection of the key case studies is presented in this technical annex.

The case studies demonstrate good practice and some failures in infrastructure resilience, highlighting **actions and attributes** that can enhance the resilience of infrastructure systems. These actions and attributes span across the six aspects of resilience: **anticipate, resist, absorb, recover, adapt,** and **transform**. By providing the examples, the Commission aims to promote good practice and tangible measures that can be taken by infrastructure operators, regulators and government to enhance resilience. More detail on the six aspects and the framework for resilience recommended by the Commission are provided in the main report of the Study.

The case studies span across the five infrastructure sectors relevant to the study: power, water, digital communications, road and rail. Flood resilience was also considered due to the cross-cutting nature of flood events and the resulting impacts on infrastructure sectors. A long list of case studies was assembled, and several cases were identified for deeper analysis. The case studies include significant recent disruptions across each of the infrastructure sectors, further demonstrating the value and timeliness of the Study.

The case studies featured in this technical annex are listed below, along with the infrastructure sectors highlighted in the case study:

1. Beast from the East 2018 – water, power
2. August 2019 power outage – power, rail
3. Summer floods 2007 and the Pitt review – power, water, roads, flooding
4. O2 network outage 2018 – telecoms, transport
5. National rail timetable disruptions 2018 – rail
6. Thames estuary 2100 plan – flooding, cross-sector
7. Forth Road Bridge closure 2015 – roads
8. Rail impacts during heatwave 2019 – rail
9. Lancashire Cryptosporidium water contamination 2015 – water
10. Lancaster winter floods 2015/16 and the Flood Resilience review – power, telecoms, flooding
11. Water resilience and regional water planning 2020 – water.

Many other cases were also considered and used in the main report of the Study, and several of these are already well documented. References are provided for further details for the following cases: Hurricane Katrina 2005,[1, 2] Hurricane Sandy 2012,[3, 4] Italian blackout September 2003,[5, 6] Baltimore tunnel fire 2001,[7, 8] Cape Town drought 2018,[9, 10] and the Toddbrook reservoir near miss 2019.[11, 12]

Some examples of actions and attributes for enhancing resilience are summarised in Table 1, with further detail provided in the following sections.

Table 1. Examples of actions and attributes to enhance each aspect of resilience

Aspect of resilience	Good practice examples of actions and attributes for enhancing the resilience of infrastructure systems
Anticipate	Assess context, risks, vulnerabilities and opportunities Develop a common understanding of expectations and standards Manage user demand and expectations Consider resilience in design Coordinate governance and planning for short, medium, and long term resilience Discover and challenge planning assumptions within and across sectors Identify, share information, and address dependencies and interdependencies Distribute and prepare resources Stress test systems and exercise response plans Monitor conditions, forecast impacts, and provide warning Pro-actively maintain systems
Resist	Take pre-emptive measures to enhance resistance or prevent impacts Prioritise resistance actions where they have the greatest potential to reduce risk Ensure defences, weatherproofing, and protection systems are in place Use multiple defences and layer defences Design systems to be safe-to-fail, and manage the consequences
Absorb	Take pre-emptive measures to enhance absorption or limit impacts Design systems to have network redundancy or buffer capacity Design systems to have localised redundancy or buffer capacity Provide a reduced service during disruptions Substitute between supplies or modes to continue to provide services Designate sacrificial zones or assets to prioritise critical systems
Recover	Take pre-emptive measures to enhance recovery and response to incidents Ensure effective governance, and decentralise as necessary Coordinate incident response Communicate consistently and effectively with stakeholders and the public Identify and prioritise vulnerable people, communities, and ecosystems Put in place measures to restart and restore services in a timely manner Rehabilitate communities and ecosystems Make arrangements for damages to be recovered
Adapt	Take opportunities to 'build back better' whilst balancing affordability Learn and share lessons and good practice within and across sectors Develop knowledge collaboratively and take collaborative action Take opportunities to provide wider benefits to society and the environment Manage and coordinate change Trial and tailor options and innovations before scaling up Keep options open for future interventions Manage uncertainty when making decisions about options and pathways
Transform	Regenerate existing systems or create new systems to meet future needs Regenerate business models and value-systems to meet future needs.

1. Beast from the East 2018

From 28 February to 1 March 2018 the UK experienced its most significant snowstorm and low temperatures since December 2010.[13] The rapid thaw that followed left over 200,000 customers across England and Wales without water for more than four hours, over 60,000 without water for more than 12 hours, and some without water for a week.[14] During the snowstorm demand for electricity jumped and demand for gas peaked at 37 per cent higher than the year previous,[15] however the energy system was able to cope with the surge in demand.[16]

The storm also caused severe transport disruptions: with roads closed, numerous traffic collisions, and cars stranded overnight on roads.[17] Rail services were cancelled[18] and air transport was severely disrupted. Thousands of schools were closed, and many areas suffered local power cuts.[19] As many as 2,000 deaths were attributed to the freezing conditions, with the UK Fuel Poverty Monitor describing the incident as leaving national and local health and social care services 'creaking at the seams'.[20] Media reports claimed the event cost the UK economy £1 billion a day.[21]

Key findings:

- Despite a similar freeze-thaw event in 2010, several water companies were under-prepared. Ofwat's review found that the variability in performance by water companies was not solely related to the severity of the weather impacts they experienced. For example, Severn Trent and United Utilities faced similar weather conditions, but Severn Trent had 100 times more customers without water after 12 hours (13,586 Severn Trent customers compared to 142 United Utilities customers),[22] suggesting United Utilities was better prepared to manage the impacts and had learnt from the freeze thaw event in 2010.[23]
- A lack of real-time data and remote control hampered some water companies from diagnosing problems and responding before loss of water supply escalated.[24] Some water companies struggled to source back-up water supplies and called on the same supplier of bottled water, and some did not have adequate incident response and escalation plans in place - including lacking coordination with external stakeholders: local resilience forums, councils and emergency services.[25]
- In some cases in the water sector, vulnerable customers were not supported due to poor record keeping and awareness by some water companies, and due to inadequate coordination with other stakeholders (e.g. local councils).[26] Many households that were adversely affected received compensation from water companies, but the amount and speed at which compensation was provided differed across companies.[27]
- National Grid Gas (NGG) issued a gas deficit warning and made several purchases to signal shippers to increase gas flows.[28] European gas prices were very high because mainland Europe gas storage was low at that time of year. Demand was met through purchases of liquefied natural gas, and from gas interconnectors with Europe. UK gas storage levels became very low before the arrival of LNG shipments.[29]

Examples of good practice and areas for improvement	
Anticipate	– The Met Office **forecasted** the conditions and issued two red warnings for snow, and multiple amber warnings for snow and ice,[30] which helped infrastructure operators prepare their staff and systems for impacts – Some water companies **planned** for the impacts and **distributed resources** prior to the event, including staff and back-up water supplies, to prepare their systems to respond – Better performing water companies had developed **a common understanding of expectations** across management, staff and stakeholders of the roles and responsibilities in preparing for and responding to the event – Real time **monitoring** in water networks helped companies to diagnose issues
Resist	– **Weather-proofing** systems and installing **defences** such as pipe insulation helped some water networks to resist or limit impacts from the snowstorm[31] – Buried pipes were better able to avoid freezing in the conditions, demonstrating the value of multiple protections and **layering of protections**
Absorb	– **Diversity in supply** and the ability to **substitute** between sources, such as water sources and fuels for electricity, helped water and energy systems to absorb impacts
Recover	– **Coordination and communication** during the response aided recovery for water companies[32] and the gas system,[33] including through pre-existing plans and mutual aid arrangements – Systems were in place to allow service providers to **prioritise vulnerable people**, however this wasn't done well by all companies – Where required by the statutory Guaranteed Standards Scheme, water companies provided **compensation** to customers adversely impacted by loss of water to aid their recovery. Some water companies also provided additional compensation
Adapt & Transform	– **Lessons were learnt and shared** via findings published by Ofwat,[34] the Drinking Water Inspectorate,[35] CCW,[36] Water UK,[37] Ofgem[38] and National Grid[39] to enable systems to be improved and better prepared for future disruptions, and to continue to monitor the effectiveness of delivery of security of supply and service availability – **Opportunities were taken** to enhance systems, including through the 2019 price review for water companies.

2. August 2019 power outage

On Friday 9 August 2019, a power outage interrupted over 1 million consumers' electricity supply across Britain.[40] Several other infrastructure services were disrupted due to the affected service providers' own safety systems or problems with their back-up power supplies, including train operating companies and Ipswich Hospital.[41] The outage occurred due to a large loss of power generation following a lightning strike on a transmission line north of London. Numerous distributed generators (such as small-scale renewables) were disconnected from the grid as a result of pre-set protection systems, and two large generators experienced technical issues near-simultaneously and were unable to continue providing power. The combined loss of generation caused the electrical frequency to fall rapidly, causing more distributed generators to disconnect from the system. Available back-up reserve power and grid stability services were insufficient to keep the system stable. The frequency then fell below 48.8 Hz and in order to protect the grid and consumers, 5 per cent of the UK's electricity demand was disconnected by automatic Low Frequency Demand Disconnections (LFDD).

Power was restored across the country within 45 minutes; however, the outage had a cascade effect, and impacts included some rail lines and disconnecting Newcastle Airport.[42] Passengers were shut out of some of the country's busiest train stations during the Friday evening rush hour, and over 500 rail services were cancelled or part cancelled. Two water treatment plants lost power and 3,000 customers experienced a decrease in water pressure when booster pumps failed. The frequency drop caused 29 Thameslink trains to fault despite power being available. 22 trains required manual engineer intervention to restart due to a software programming error, creating disruptions to rail services for several hours. Train services were restored in full within 24 hours.[43]

The two large power generators voluntarily payed £4.5 million each into the Energy Industry Voluntary Redress Scheme for their part in the power outage.[44] Additionally, two Distribution Network Operators (DNOs) paid £1.5 million into the redress fund because they prematurely re-connected customers before National Grid Electricity System Operator (ESO) gave approval, endangering recovery of the system. Ofgem, the Energy Emergencies Executive Committee (E3C), and the ESO made recommendations to enhance resilience in the power sector, and the ORR made recommendations to Network Rail and train companies to prevent similar failures in future.[45]

Key findings:

- Ofgem found that National Grid ESO was not in breach of its requirements. However, Ofgem suggested areas of improvement for the ESO regarding validating performance of generators and response providers, and communicating with stakeholders during incidents. Ofgem recommended measures to enhance the response and management of the system in future events, and the need to reassess the ESO's role and security of supply in order to meet the challenges of the decarbonising the grid.
- The ESO was holding 1,000MW in power reserves, however more than twice this amount of generation was lost. As a standard, while ESO holds sufficient back-up for the loss of the largest generator from the network (N-1), it does not carry back-up to account for the concurrent loss of distributed generators or a second large generator (N-2). The event draws into question whether there would be a cost-benefit to hold more reserve power, or whether this would provide little additional resilience at a large cost. The ESO has formed a working group to answer this question.[46] A similar event (co-incident loss of large generators) took place in 2008.[47]

- There is a lack of visibility and real-time data available to DNOs and ESO from distributed generators, making it harder to manage the electricity system. Ofgem is considering changes to industry codes and licenses to enhance operational monitoring and make the system better prepared for when DNOs transition to Distribution Systems Operators (DSOs).
- Whilst increasing numbers of renewable asynchronous generators did not cause the incident, they reduce inertia in the electricity system, which reduces the available response time for the ESO to restore frequency drops.[48] Countering this, new technologies and innovations including batteries and synchronous compensators can be brought online faster than traditional generation to fill the power-supply gap.[49]

Examples of good practice and areas for improvement	
Anticipate	– Some infrastructure operators failed to **manage dependencies** to avoid failures in the energy system cascading across infrastructure systems – The affected infrastructure operators and power users may have been able to identify vulnerabilities in their systems by **stress testing** their systems (including software) and their back-ups, and **exercising response plans** – Ofgem found that a lack of **real-time monitoring and data** for distributed generators impeded electricity operators' ability to anticipate and understand issues
Resist	– **Protection systems** were used, such as those on the transmission network which cleared the fault following the lightning strike[50]
Absorb	– **Network capacity and back-up reserves** helped the grid to absorb and recover – **Localised back-up**, such as batteries at hospitals, helped users absorb impacts
Recover	– Ofgem found that improvements could be made to better **coordinate during incident response**, in order to prevent misalignment of actions and ensure **consistent communications** with the public – The voluntary **contributions to the redress scheme** aid recovery
Adapt & transform	– **Lessons were learnt and shared** via findings from Ofgem,[51] E3C,[52] ESO,[53] and ORR[54] – **Change is being implemented and managed** to improve systems, for example the protection systems on distributed generators are being upgraded to reduce the chance of disconnection for a similar event in the future.

3. Summer 2007 floods and the Pitt Review

Record rainfall in June and July 2007 resulted in widespread flooding across the UK, particularly in Yorkshire, Worcestershire, Gloucestershire, and Oxfordshire.[55, 56, 57] 13 people died, over 55,000 homes and businesses were flooded causing £3 billion of damage and requiring 7,000 people to be rescued from flood waters.[58] Authorities described the rescue efforts as the biggest in peacetime Britain. Over 350,000 people in Gloucestershire lost water supplies for 17 days after flooding of Mythe water treatment works. Castle Meads electricity substation was shut down due to rising flood water, leaving 42,000 people in Gloucester without power for up to 24 hours. Many major roads, railway stations and lines were closed, including the M5 where 10,000 people were left trapped overnight.

Significant near misses avoided further devastation, including avoiding flooding at Walham substation (serving 500,000 people in Gloucestershire and south Wales) and a number of electricity substations around Sheffield (serving 750,000 people). A catastrophic dam breach at Ulley reservoir, Rotherham, was narrowly averted and 1,000 people were evacuated as a precaution. The breach endangered life, the M1 motorway, a major electricity substation and the gas network connection for Sheffield.[59]

The review that followed was one of the widest ranging policy reviews ever carried out in the UK, chaired by Sir Michael Pitt.[60] The review made 92 recommendations which were all supported by the government at the time.[61] The event and the review catalysed system-change which has enhanced planning, flood forecasting, and emergency response.

Key findings:

- Following the Pitt Review, the Environment Agency has taken on the national overview role for all types of flooding and coastal erosion, developed inter-area mutual aid protocols, and invested in strategic stocks of temporary defences and pumps.[62] The Flood Forecasting Centre[63] was established, developing long range forecasting to enable timely deployment of resources such as temporary barriers. The Natural Hazards Partnership[64] was created to provide advice to Cabinet Office on reasonable worse case flooding planning scenarios for the National Risk Register.[65] Additionally, billions of pounds were spent building flood defences.[66] Resilience has improved by strengthening the role of Local Resilience Forums, developing sector-wide resilience plans for essential services, and conducting flood vulnerability assessments for infrastructure systems.[67] From 2013 the Environment Agency became the regulator for reservoir safety.
- The Pitt Review emphasised the need to adapt to the inevitable impacts of climate change. It urged increased investment in adaptation, and highlighted that severe weather events will become more frequent and more intense.[68] There is growing evidence this is occurring,[69] and during flooding in 2012 rainfall surpassed the record set during summer 2007.[70]
- Several of the Pitt Review's recommendations lagged in implementation,[71] and the government has taken alternative courses of action on some of these.[72, 73] These include changes to building regulations to make homes more resilient to flooding, where the government has developed guidance and standards, rather than formal requirements. Implementation of sustainable drainage systems (SuDS) was strengthened in the National Planning Policy Framework 2019.[74] However, the government has decided against implementing an authority to manage and oversee SuDS, and against removing the right of new developments to connect to the public sewer system, stating that these do not provide clear benefits over current arrangements.[75]

- The flooding of Mythe water treatment works represented the most significant loss of essential services since the Second World War. It raised questions about the dependency of large populations on a single critical asset with only limited storage capacity and no interconnectivity with back-up supplies.[76] When the public heard media reports that supplies from Mythe water treatment works would be lost, people filled up their own storages which exacerbated the situation and supplies were lost within 12 hours instead of the planned 36 hour storage.
- Calling on the same supplies of back-up equipment delayed some of the response. For example, temporary pumps to alleviate the flooding in Hull were not available because they were already being used to avoid the larger emergency at the Ulley dam.[77]

Examples of good practice and areas for improvement	
Anticipate	– By developing a **common understanding of expectations** across agencies and stakeholders, some were better equipped to cope with and respond to disruptions – **Forecasting and warning** provided valuable time to allow systems and communities to prepare for shocks, however following the floods forecasting was greatly enhanced
Resist	– **Defences** played an important part in safeguarding systems from flooding, including defences which are constructed, nature-based, and temporary – **Safe-to-fail** systems were used to direct flood water to **sacrificial zones** whilst protecting critical systems[78]
Absorb	– **Pre-emptive measures** were taken to help systems absorb the impacts of the floods, such as pre-emptively reducing reservoir levels and **rerouting** transport services as a precaution – **Network capacity** through interconnected water systems prevented loss of water to thousands of customers. However, the case shows the limitations of interconnected networks that relied on a single water treatment works which failed
Recover	– **Coordination during the incident response** prevented misalignment of actions between responders, and allowed mutual aid to be sought – **Consistent communications** with the public and **leadership** by senior figures helped to ease the stress for people and provide reassurance that the situation would be managed – **Communities and ecosystems were rehabilitated** following the floods
Adapt & transform	– **Lessons were learnt and shared** via the Pitt Review and various other reviews[79] – **Knowledge was developed and action taken collaboratively** to establish the Flood Forecasting Centre – **Opportunities to 'build back better' were taken** in some cases with enhanced flood defences and catchment approaches, however some recommendations from the Pitt review have not been fully implemented, and vulnerabilities remain. – The Pitt review aspired for **regeneration and transformation**, through building new systems as well as through raising aspirations, improving skills, and improving the environment.[80]

4. O2 network outage 2018

On 6 December 2018, mobile company O2 suffered a major outage affecting 25 million of its customers in the UK[81] and up to 7 million customers of service providers that use the Telefónica UK network. The outage started at 04:30 and lasted up to 23 hours, affecting 2G, 3G and 4G data services. It was the largest disruption to mobile data services in the UK's history. An expired security certificate in critical software provided by O2's supplier, Ericsson, caused the disruption.[82] This software created issues for several of Ericsson's customers' networks across the globe.

2G and 3G services were restored by 21:30, and 4G services were restored by 03:12 the next day.[83] The media reported cascading impacts from the outage affecting Transport for London's (TfL) live travel updates for buses, London's Santander cycle terminals, and payment services in some shops, taxis, and carparking ticket machines.[84, 85]

Key findings:

- Recognising the large disruption for customers, Ofcom carried out an investigation and found that O2 had not contravened its obligations due to the fact that O2 could have not reasonably been expected to have known about the cause of the problem.[86] O2 responded well to the incident; O2's major incident management team was engaged within 20 minutes of the outage, progress was reported to the Telefónica UK Board Major Incident Management team and CEO, and O2 swiftly communicated with Ericsson to resolve issues. To avoid potential network congestion, or overload of the network, some phone and text services were affected as data services were gradually restored.
- The media reported that as goodwill, O2 offered compensation to 25 million of its customers, however this did not include customers of other services that relied on O2's systems.[87] The compensation reportedly differed between pay-as-you-go customers and contract customers, and was decided by O2, rather than based on a standard or industry guide.
- Media reports suggest certain groups were particularly impacted by the outage, such as those who work outside office environments, including tradespeople, drivers who rely on mobile maps, the self-employed and small businesses.[88]
- Digital network failures are likely to become more disruptive in future as the number of people working outside the office increases, and as more services and devices depend on digital networks, for example through the internet-of-things (IoT).
- A software fault was responsible for the network interruption, suggesting investments in physical resilience measures and cyber resilience would not have prevented this event. The case is an example of the wide range of vulnerabilities which exist for infrastructure systems.

Examples of good practice and areas for improvement	
Anticipate	– **Planning** for network management and incident response helped O2's systems to better manage and recover from the disruption – The case highlights that **managing dependencies** includes appropriate arrangements with suppliers and contingencies if their services are disrupted
Resist	– **Defences and firewalls** play a part in safeguarding systems and software, but other software vulnerabilities may require specialised approaches
Absorb	– Prioritising restoration of some services before others provided customer with a **reduced service**, which may have eased the disruption for many customers
Recover	– **Timely restoration of services** reduced the impacts on customers – **Communication and coordination** between O2's incident management team, O2's senior management, and Ericsson during the response aided recovery. O2 also communicated with Ofcom and the Department for Digital, Culture, Media and Sport as required. – **Compensation** was offered to O2's customers to assist their recovery of damages
Adapt & transform	– **Lessons were learnt and shared** via a review by Ofcom[89] – **Knowledge has been developed** and guidance produced to improve systems.

5. National rail timetable disruption 2018

After major upgrades to parts of Britain's railway network and investment in new trains, a new national rail timetable was introduced on 20 May 2018.[90] The upgrades aimed to facilitate thousands of new train services, and additional capacity for tens of thousands of rail passengers. The scale of investment and complexity of introducing new services meant the changes were unprecedented in scale, having complex effects across multiple rail service operators and large portions of the national rail network, involving 42,300 individual service changes and affecting 46 per cent of all passenger services.[91] It was around four times the scale of a typical six-monthly timetable change. The changes were overseen by the publicly-owned infrastructure owner, Network Rail, and privately-owned train operating companies Arriva Rail North (ARN) and Govia Thameslink Railway (GTR). The Department for Transport (DfT) and the Office of Rail and Road (ORR) were also involved in discussions.

Following the changes, there were major disruptions to services for up to two weeks in Northern England and eight weeks in South East England, and ongoing disruption over a longer period. GTR failed to run 12 per cent of its planned daily services, and ARN failed to run 11 per cent of its weekday services.[92] There were also substantial knock-on effects on TransPennine Express and other operators across the network. Peak time services that did run were often crowded and extremely unreliable. The number of delayed services on GTR more than trebled, and ARN's delays doubled before stabilising upon introduction of an emergency timetable on 4 June. GTR continued to run a haphazard emergency timetable until 15 July, when it introduced an interim timetable. The disruption caused strain on people's mental health as passengers were late for work and children were late for school,[93] some couldn't get home at night, and many passengers were forced to spend money getting taxis.[94]

Key findings:

- ORR found there were systemic weaknesses in the planning and delivery of the major network changes required in preparation for the new timetable, and "no one took charge".[95] Key weaknesses originated at the project sponsorship level, where proper independent assurance was not sought about the delivery of major programmes or that risks were being identified and managed.
- The Transport Select Committee (TSC) found there was "a collective, system-wide failure" and that "governance and decision-making structures were fundamentally flawed".[96] Despite the industry's long-established processes and timeline for changing the national rail timetable every six months, processes were not followed. There were programme management and system integration failures. TSC recommended that in future the national rail timetabling process has independent oversight and an independent Project Sponsor by a senior owner outside of Network Rail, so that the role is effectively insulated from commercial and political pressures.
- The TSC found room for improvement by all parties involved.[97] Network Rail's infrastructure project teams and the train operating companies were "guilty of an indefensible optimism bias". The governance and decision-making structures overseen by the Secretary of State (SoS) and the DfT "were inadequate", and the even though the SoS was not fully informed of serious problems, "he should have been more proactive". The review also found the ORR "missed chances to sound the alarm" and "a more effective regulator may have been able to avert the crisis".

- Significant delays in completing the upgrade projects to the rail infrastructure meant there wasn't sufficient time to train drivers and agree train operation schedules.[98] The case highlights that change requires effective governance and management, and must allow sufficient time for engagement with employees and the public.
- Disabled passengers were disproportionately affected and there were insufficient measures in place at the regulator level and operations level to protect vulnerable passengers.[99]
- GTR was fined £5 million for failing to appropriately balance the steps it was taking to improve services with the need for passenger information to an unacceptable extent and duration.[100] ARN was not fined, as ORR considered ARN took reasonable steps to provide appropriate, accurate and timely information to passengers, including introducing an interim timetable on 4 June.
- Following the event, the government launched the Williams Rail Review in September 2018 aiming to deliver 'revolution' not 'evolution' in rail services by making recommendations on the most appropriate organisational and commercial frameworks to deliver the government's vision for UK rail.[101] The review was due to be complete in 2019 but is now expected in 2020.

Examples of good practice and areas for improvement	
Anticipate	– ORR found that major programme **risks were not sufficiently identified and managed** – The case highlights the need for a c**ommon understanding of expectations** across parties to prepare systems for change – **Coordinated design and planning** for the integration of network upgrades could have been enhanced to better prepare rail systems for the change. This could include **challenging assumptions and better managing risks** – Train companies could have improved the way they managed demand and customer expectations ahead of and during the disruptions
Resist	– The reviews found that several parties **missed opportunities to prevent the issues**
Absorb	– Train companies introduced interim timetables with **reduced services** to reduce the impact of the disruptions on customers – Train companies provided **substitute modes** of transport to support some customers, including busses and taxis in some cases
Recover	– **Communication** with customers is essential during recovery, and was identified as an area that wasn't adequately managed by train companies
Adapt & transform	– **Lessons were learnt and shared** via reviews by the Transport Select Committee[102] and the ORR[103] – **Change was managed and implemented**. An industry Programme Management Office has been established and has overseen the introduction of new timetables from December 2018 onwards.[104] This arrangement has delivered improvements, but ORR has said more is needed to address systemic risks – The Williams Review is a major review into the provision of rail services with the potential to drive **transformation** in the sector.

6. Thames estuary 2100 plan

The Thames estuary 2100 plan (TE2100) is the Environment Agency's strategy for managing tidal flood risk in the Thames estuary to the end of the century and beyond, protecting 1.3 million people and £275 billion worth of property from tidal flooding.[105] Following 10 years of research and planning, the plan was approved by Defra in 2012.[106] TE2100 advances the shift from traditional 'flood defence' to 'flood resilience', through its long-term horizon, estuary-wide approach, and emphasis on floodplain management. The £10 billion plan is adaptable to differing rates of sea level rise and flood risk through combining different options to enhance London's system of flood defences, including the Thames Barrier, and community-level interventions. The plan also includes creation of new habitats to compensate for those lost due to sea-level rise.[107]

Key findings:

- TE2100 demonstrates a system-wide adaptive approach to resilience. It considers interventions ranging from physical interventions (at source, pathway and receptor), planning (floodplain management), governance, and community level, as well as allowing for options to be developed in the future based on growth or changing attitudes to risk.
- The strategy is adaptive in order to deal with the uncertainty associated with climate change and wider uncertainty. It identifies decision points with associated options to maintain a defined level of flood resilience over time, as opposed to being a static plan committing investment to deliver pre-defined flood defences. The benefit of this adaptive approach means that decisions on large upfront investments have been delayed until the decision point is reached, allowing the decision to be made based on the most up to date science and understanding of need. This helps to avoid over and under investment, options for future interventions remain open until needed, and resilience is achieved over time.
- Adaptive management for the plan includes monitoring and reviewing progress every 5 years and adapting the plan based on the latest evidence available at the time. 10 key indicators are monitored to alert decision-makers to when decisions need to be made, acting as trigger points for bringing forward or changing interventions to manage flooding. The 10 indicators include physical and societal indicators: mean sea level, peak surge tide level, peak river flood flows, condition of flood defence structures, frequency of closure and reliability of barriers (Thames and other barriers), developed area and type of development, extent of erosion and deposition, intertidal habitat area, land use planning and development activities, and public and institutional attitudes to flood risk.[108]
- A review in 2016 found that changes in the estuary are generally in line with the original forecasts, and therefore decision points identified in TE2100 remain appropriate, meaning adaptation options did not need to be changed or brought forward.[109] The second 5 year review is currently underway.
- The plan currently identifies a decision being made around 2050 on the best option to protect London up to 2100. The front runner options currently identified are to enhance existing defences, and to build a new barrier at Long Reach.[110] Due to the UK's Net Zero emissions target, the need for future interventions to be constructed with very low carbon footprints will need to be addressed in future reviews of TE2100.

- According to some commentators, there are elements of TE2100 that could have been improved,[111] including enhanced collaboration and ownership at a local borough level, enhanced enforcement of floodplain management to curb property development in flood-risk areas, and greater clarity on funding sources and how costs could be equitably distributed. These lessons can be applied to future approaches for enhancing resilience across sectors.

Examples of good practice and areas for improvement	
Anticipate	– Evidenced-based **analysis and forecasting** was used to develop the plan over a 10 year period – **Coordinated design and planning** is achieved by taking a system-wide view of flood resilience across the estuary and integrating spatial planning, environmental management, flood defence schemes, and community-level interventions – **Monitoring** ten key indicators over time is central to allow adaptive management of the plan and trigger decisions about implementing interventions
Resist	– TE2100 includes a range of options to help prevent flooding from source to receptor, including **natural and built defences** and **property level measures** – During a tidal surge, **pre-emptive actions** can be taken to help resist impacts, such as by closing the Thames barrier
Absorb	– TE2100 options included managed realignment on the outer marshes as **sacrificial zones**. This is multi-beneficial as it decreases peak water levels in the centre of London, creates habitat and allows for formal defences be moved to a more sustainable alignment. Overall the proposed managed realignments allow the estuary to absorb more of the water and energy from future storm surges.
Recover	– The plan includes **compensating for habitats** lost to sea level rise
Adapt & transform	– **Options are kept open** to bring forward interventions in the plan, to scale up interventions, or to adopt new approaches as an when they are needed – Constructed flood schemes are built with **flexibility** to allow them to be raised or strengthened in future – **Options aim to deliver multiple benefits** beyond flood resilience. For example natural flood defence schemes can enhance biodiversity, sequester carbon, and improve water quality. Options also include making space for the Thames Path – **Good practice is shared** through publication of TE2100[112] and five year updates.[113]

7. Forth Road Bridge closure 2015

Forth Road Bridge (FRB) crosses the Firth of Forth 15 kilometres west of Edinburgh and is a vital link in Scotland's strategic road network used by over 70,000 vehicles a day.[114] The bridge underwent emergency closure on 4 December 2015 after cracks were discovered in the steel truss end links under the carriageway by the bridge operator Amey.[115]

The closure caused severe disruption to travellers between Edinburgh and Fife, exacerbated by the increased traffic in the lead up to Christmas. Additional buses and trains were scheduled to take people from Fife into Edinburgh, but the Kincardine and Clackmannan Bridges remained extremely congested with long delays encountered throughout the day.[116] Following a series of temporary repairs, the FRB re-opened to traffic, except heavy goods vehicles (HGVs) and abnormal loads, on 23 December 2015.[117] After further improvement works, HGVs were permitted to use the bridge again on 20 February 2016.

The closure of the bridge was estimated to cost the economy £1 million per day,[118] and created immense strain for commuters with many people late to work and some local businesses suffered significantly from lost business.[119] The haulage industry was particularly badly affected: lorry drivers had to drive an extra 60 mile round trip, adding £30 in fuel costs each trip and causing increased stress, in some cases for up to 2 months.[120]

Key findings:

- The planned capacity for the bridge when it was built in 1964 was 30,000 vehicles per day, but in 2015 upward of 70,000 vehicles used the bridge each day. The bridge was also carrying twice the weight it was originally designed for.[121] The failure of the truss end links demonstrates the vulnerability of older infrastructure over time and under high loading. Fortunately, a robust risk-based maintenance and inspection regime was in place, and is the reason the failure was discovered before a serious incident occurred.[122]
- A review in 2016 by the Infrastructure and Capital Investment Committee for the Scottish Parliament found that the failure of the steel truss end links was unforeseeable.[123] The review found that in 2011 the Forth Estuary Transport Authority (FETA) reprioritised projects within its capital plan – including deferring work to address the efficacy of the truss end link mechanisms.[124, 125] The Committee's view was that the decision by FETA to reprioritise capital projects was a direct consequence of a decision by the Scottish Government and Transport Scotland to reduce FETA's capital grant allocation for the period 2012/13 to 2014/15. In light of the reduced budget and in the absence of significant engineering concerns, the Committee's view was that FETA acted entirely appropriately. The majority of the Committee felt that FETA had the option to go back to Transport Scotland to make a case for additional funding, had FETA felt the work to be necessary from a public safety perspective.
- After structural issues in the FRB were identified in 2005,[126] plans to build a replacement crossing were advanced and it was decided in 2007[127] to build the Queensferry Crossing. This decision was pre-emptive in managing risks, however the Committee's view was that the Queensferry Crossing project influenced decisions to reprioritise capital projects for FRB.[128]

- Social research conducted during and after the 3-week bridge closure highlighted the need for effective businesses contingency planning and adapting to flexible or remote working to reduce the need for people to travel in the event of major transport disruptions.[129, 130] The research recommended that contingency measures and communications should be targeted to reach different user groups and communities in order to enhance resilience when major disruptions occur. This could include providing travel advice to people, as well as suggesting flexible working arrangements to businesses.

Examples of good practice and areas for improvement	
Anticipate	– Structural health **condition monitoring** technology was not installed on the truss end links of the FRB until after the incident occurred.[131] This technology now provides valuable data to help anticipate issues before they arise. – **Risk-based inspections, proactive maintenance, and capital upgrades** were carried out on the FRB. However, decisions to reprioritise certain works did not prevent the failure of the truss-end links.[132]
Resist	– To prevent the bridge from a catastrophic failure, pre-emptive measures were taken by closing lanes of the bridge to traffic, followed by closing the bridge completely, to address issues
Absorb	– **Substitute modes of transport** were arranged to allow commuters alternative means of travel, including increased numbers of busses and trains, and an official detour route was established[133]
Recover	– Transport Scotland launched a temporary travel plan providing commuters with **information on contingency measures** and alternative routes[134] – To ease the financial burden on commuters imposed by the closure of FRB, Transport Scotland temporarily **reduced fares** for buses[135] – **Repair works were carried out at pace**, despite periods of adverse weather. The review stated this was 'a remarkable engineering achievement'[136]
Adapt & transform	– Lessons were learnt and shared following the review by the Infrastructure and Capital Investment Committee for the Scottish Parliament[137] – **Opportunities were taken** to enhance resilience by upgrading the bridge – The Queensferry Crossing was opened to create a new transport link and permanently reduce pressure on the FRB, delivering a **step-change** in resilience.

8. Rail impacts during heatwave 2019

Europe experienced a short but exceptional heatwave in late July 2019 where the UK, Belgium, the Netherlands, Germany, and Paris recorded their highest temperatures on record.[138] The UK rail network was severely affected across south-east England with train cancellations and main lines closed out of London due to concerns with potential rail buckling.[139] Network Rail (NR) introduced speed restrictions to manage the risks of buckling, which required a number of train services to be cancelled and therefore some services became busier. Damage occurred to overhead electric wires as they sagged in the heat, and trackside vegetation caught fire in several locations.[140] The exceptionally hot weather made conditions difficult, particularly for the frail and elderly. 570 deaths were attributed to the heatwaves in the UK, almost all were people aged 65 or over.[141]

Key findings:

- NR's Weather Resilience and Climate Change Adaptation (WRCCA) strategy is based on building resilience through improved planning and decision-making around climate change, asset renewal replacing 'like' for 'better', and increased collaboration across the rail industry.[142] Through this approach, resilience will be enhanced incrementally over time within cost constraints, rather than through a major investment delivering a step-change in resilience.
- In the meantime, NR has pre-emptive actions in place to try to limit disruption to services and respond to failures. For example, to avoid rail tracks buckling in heat, NR stresses rails and carries out a range of other preventive activities including using dedicated teams to paint known-hot spots in the tracks white.[143] The paint solution, however, doesn't address the root cause of vulnerabilities that are set to increase with climate change.
- NR said that for rails to withstand climate conditions from sub-zero to over 35°C, construction costs are fourfold higher, and costs also increase during operation.[144] For example – some tracks may need to be physically adjusted from summer to winter. NR has stated it is neither practical nor cost effective to implement these measures permanently across the network.
- NR's WRCCA strategy was developed in 2017, however climate projections were updated in 2018 and project London temperatures will be the same as Paris is now by 2050.[145] The strategy focuses on floods and high winds, with little mention of heatwaves. This suggests a need to update the strategy and action plans to account for the latest forecasts and future scenarios.

Examples of good practice and areas for improvement	
Anticipate	– NR have committed to **design for resilience** for new rail infrastructure investments – **Demand and customer expectations** were managed by notifying customers ahead of disruptions and advising them to avoid travel if they didn't need to[146]
Resist	– NR takes **pre-emptive measures** to help infrastructure resist heatwaves, such as **weatherproofing** electrical systems, stressing rails, and painting hot-spots white[147]
Absorb	– Train companies ran **reduced services a**t slower speeds to provide a level of service and reduce the risk of trains buckling on the tracks. – Train companies provided **substitute modes** of transport to support some customers, including busses
Recover	– NR's extreme weather action teams (EWATs) **pre-empt areas at risk** to enable faster response and resolve incidents to **restore and maintain services**
Adapt & transform	– NR have committed to **building back better** when weather events cause assets to catastrophically fail[148] – NR have committed to **taking opportunities to adapt** through incremental asset renewal. However, more investment may be necessary to prepare for future heatwaves.

9. Lancashire Cryptosporidium water contamination 2015

In August and September 2015 a major drinking water quality emergency occurred in north Lancashire, affecting more than 700,000 consumers.[149] United Utilities (UU) identified Cryptosporidium in water supplied from the company's Franklaw water treatment works. Cryptosporidium is a parasitic protozoa causing gastric illness in humans.

On 6 August UU advised all consumers supplied with water from Franklaw (10% of its customers) to boil their tap water before using it for drinking and food preparation. Franklaw treatment works was the sole source of supply to the affected consumers in Blackpool, Preston and the Fylde coast, and the advice to boil water was in place for up to a month for some consumers, causing significant concern to some people and businesses. Fortunately the risks were managed by the way UU responded, and Public Health England reported that there were no identified cases of cryptosporidiosis illness.[150]

It is the largest incident of its kind in Britain since 1989 when the water industry in England and Wales was privatised.[151] The Drinking Water Inspectorate (DWI) concluded that the incident was caused by a number of significant failings in the operation of the Franklaw works and inadequate risk assessment of major operational changes. In 2017 UU was fined £300,000 over the incident and additional costs of £150,000 were agreed with the DWI.[152] The incident cost UU £25 million due to customer compensation payments, and one-off costs to recover from the incident.[153]

Key findings:

- The definitive cause of the contamination was not established, but in December 2015 UU determined that the most likely cause was direct contamination of treated water stored in Barnacre service reservoir.[154] Contamination occurred through structural defects in the service reservoir that allowed ingress of faecally contaminated water. This water was likely run-off water from agricultural land following heavy rainfall, which was able to enter the underground water tank. Despite regular inspections, it's likely a joint on the tank was affected by small ground movements in the tank structure. Immediately before Cryptosporidum was detected, UU had used water from Barnacre reservoir to supply the service water system at the Franklaw works, which meant that contaminated water was introduced into the treatment process before and after the treatment stages which remove Cryptosporidium.[155]
- Because of operational constraints associated with the complexity of the supply system and the large sizes of some the service reservoirs, UU was not able to isolate and clean out all of the reservoirs in the Franklaw system quickly enough to allow early lifting of the Boil Water Notice. Therefore, the company had to install emergency ultraviolet (UV) disinfection treatment on reservoir outlets in the supply system and other key strategic water treatment sites.[156] UV provides additional protection, but increases operating and maintenance costs and carbon emissions. While it was deemed necessary to protect public health, it highlights the challenge with delivering resilience affordably whilst meeting other objectives – such as reducing energy consumption and optimising investment.
- There have been several previous events involving contamination of drinking water from Cryptosporidium. Anglian Water's Pitsford treatment works was contaminated in 2008 when a rabbit entered an open ventilation hatch in a tank of service water used to backwash filters.[157, 158] The two cases demonstrate risk assessment and mitigation measures falling below standard for good operational practice and regulatory requirements.

Examples of good practice and areas for improvement	
Anticipate	– UU had routine water quality **sampling and monitoring** in place which detected the contamination in early August and allowed UU to initiate measures to resist impacts and respond. However, the design of the interconnected water supply system limited UU's options.
Resist	– As a **pre-emptive measure** to protect public health, UU issued a Boil Water Notice as a precaution before it was established that there was a risk to consumers throughout the distribution network – During the incident, UV treatment was installed as a **treatment barrier** to protect drinking water supplies – In some cases, **interconnectedness of supply** networks can enhance resilience, for example if one of the supplies is taken offline, others are already connected to provide back-up. However, in this case the complexity of the supply system compounded the issue because reservoirs could not be easily **isolated and cleaned**.[159] This demonstrates an example of unintended consequences of interconnected systems.
Absorb	– During the incident, UU delivered over one million litres of bottled water to local schools and authorities as a **substitute** to using tap water supply[160]
Recover	– UU **communicated transparently** and made customers aware of the Boil Water Notice through various channels, including television, local radio, newspapers, website updates and social media[161] – UU made an average **compensation payment** of £50-£60 per customer to recognise the considerable inconvenience customers faced[162]
Adapt & transform	– **Lessons were learnt and shared** via DWI's review[163] and UU's training materials[164] – Opportunities were taken to **'build back better'** through installation of UV treatment at several treatment works, providing a higher degree of protection to water supplies.

10. Lancaster winter floods 2015/16 and the National Flood Resilience review

December 2015 was the wettest month on record in the UK since 1910, and a series of storms (including Desmond and Eva) resulted in heavy and sustained rainfall.[165] Heavy rain from Friday 4 to Sunday 6 December led to widespread flooding in Cumbria and across parts of northern England.[166]

There were two fatalities and the floods caused £1.6 billion in damage.[167] 17,600 properties flooded, and several bridges collapsed, disrupting access to and from communities. Many road and rail links were cut, including the West Coast Main Line. Schools and hospitals were closed in the flood affected areas. The highest flow of any river ever recorded in England occurred on the River Lune, which flooded Lancaster.[168]

At 22:45 on Saturday 5 December electricity supplies to 61,000 properties in Lancaster were cut when flood defences were breached at the Lancaster substation.[169, 170] Without power, communication services were severely impacted, hampering recovery efforts.[171] People lost mobile phone reception, cordless phones lost power, and television, radio and internet were cut. Traffic lights failed, fuel stations could not pump fuel, high-rise buildings could not pump water or operate lifts, and businesses were forced to close without lighting and electronic payment systems. The railway remained active because it was powered from outside the area, but the railway station lost power so was closed for some periods due to safety reasons.

Electricity was progressively restored from 04:30 on Monday but was cut again to most areas at 16:00 that evening. Electricity North West (ENWL), the owner of the substation, arranged for 75 large diesel generators to be delivered to the city and connected to local substations which allowed restoration of supplies over the next few days.[172] This was a substantial challenge requiring almost every portable generator in the UK. By Friday 11 December, power had been restored to all customers across the region. Following the event, the government launched the National Flood Resilience Review (NFRR) in September 2016 to better understand the risks and enhance resilience for energy, water, transport and communications infrastructure.[173]

Key findings:

- The impacts arising from the loss of power in Lancaster demonstrates the high dependency of many services on electricity, particularly communications infrastructure. There was no formal governance or process for coordination and response across the energy and communications companies.[174] Some companies had conflicting incentives - either to maximise profit or to minimise their regulated asset base - which impeded overall resilience. For example, supplying backup power to neighbourhood broadband routers could impose costs on power or telecom companies, and arrangements to share costs between companies can be complex or inhibited by regulation.
- Ofgem stated that this event, along with other storms experienced over the 2015/16 winter period demonstrate the need for the regular review of network resilience by the network companies, underpinned by monitoring of impacts, and use of the latest science and information available on potential climate impacts at a national and local level.[175]

- The NFRR conducted stress tests to determine the risks to infrastructure sectors by determining plausible rainfall and flooding events over the following decade.[176] However, the review excluded surface water flooding, instead pointing to other reviews which cover surface water, including the National Risk Register.[177]
- The NFRR recommended that water and telecom infrastructure companies develop resilience plans for 530 vulnerable sites to bring them into line with plans developed in the power sector.[178] This included buying and storing temporary flood barriers, and putting in place plans to deploy them in the event of a flood. The power sector had these measures in place following funding post the Pitt Review, however several water and telecoms companies didn't have the funding or didn't prioritise this approach until after it was formally recommended. Investment following the NFRR was significant, and in some cases exceeded the requirements of the review.
- The NFRR found that describing flood risk in traditional terms such as a '1 per cent chance of flooding' or '1 in 100 year risk' is not helpful because it's very likely to be misinterpreted.[179] The terms describe the flood risk at a specific location, however does not describe the chance of the event happening somewhere in the country or region in a given year – which is much greater. Nor do they describe the impact on people and on the economy when events that have previously been regarded as very unlikely do happen. This finding demonstrates a lack of understanding and planning for low probability, high impact events.

Examples of good practice and areas for improvement	
Anticipate	– The Met office **forecasted weather conditions** with good lead times, and the Flood Forecasting Centre **provided warning** of an extreme flood event – Following the incident, the NFRR completed **stress testing** and **vulnerability assessments** to determine the flood risk of critical sites – **Interdependencies were not addressed** between power and communication infrastructure prior to the incident, and when power failed recovery was hampered – The NFRR emphasised a focus at the network level rather than at the level of individual assets, using a **system-based approach to planning for resilience**
Resist	– ENWL invested £7.9 million in **flood defences** at major sites prior to the floods, including in 2010 at Lancaster substation, to protect against a 1 in 100 year flood,[180] but the volume of rainfall exceeded forecast models – ENWL used **temporary barriers** to protect Lancaster substation, however these were limited in their ability to resist flooding
Absorb	– If there were **redundancy measures or back-up** power supplies in place, impacts may have been reduced for services that rely on power – There were insufficient **fallback options** for communications. Emergency systems may have been able to provide a reduced service to customers, such as through the use of temporary mobile stations or satellite technology.

Examples of good practice and areas for improvement	
Recover	– ENWL responded rapidly to r**estore services**, obtaining generators to **temporarily supply** power[181] – The government put in place a **recovery package** for homes, businesses and farms in flood affected areas to help get communities back on their feet and to strengthen defences[182] – Following the floods and prior to the NFRR, the Flood Re **insurance** scheme was established and replaced an existing scheme. Flood Re aims to ensure households at high flood risk can continue to obtain flood insurance at affordable cost[183]
Adapt & transform	– To manage flood risk in future, options were implemented which **provide multiple benefits**, such as catchment management and natural flood management measures; reducing flood risk, enhancing ecosystems, improving water quality, and sequestering carbon[184] – **Lessons were learnt and shared** through publication of the national flood resilience review,[185] and best practice guidance from the Environment Agency[186] – **Knowledge is being developed collaboratively to enable action**. The Electronic Communications Resilience and Response Group (EC-RRG)[187] has identified 'developing understanding of other sectors and agreeing specific resilience measures' as one of their five key priorities for 2020/21.

11. Water resilience and regional water planning 2020

The UK has experienced serious droughts once or twice a decade over the past 50 years,[188] whilst demand for water is increasing in some parts of the country. Without concerted action, the risk of parts of England running out of water could become intolerably high within the next two decades.[189] To manage this risk, water companies in England and Wales are required to prepare revised water resources management plans (WRMPs) every five years, setting out how they intend to balance water supply and demand over at least the next 25 years.[190]

In the past, water companies have primarily focused on meeting their own needs in isolation, through measures within their own geographical boundaries and catchments. A significant change is underway in England, with development of the national framework for water resources.[191] The framework strengthens the role of regional planning by five regional groups, made up of the 17 English water companies and other major water users and stakeholders. Some regional groups have been in existence for several years, whereas others have been newly established. The national framework has been led by the Environment Agency (EA) and developed through collaboration with Defra, Ofwat, the Drinking Water Inspectorate (DWI), Natural England, Natural Resources Wales, and the 17 English water companies. By considering the needs of England as a whole – including sectors often outside of public water supply, such as agriculture, industry, and power generation - the national framework aims to deliver a step-change in resilience and environmental protection.

The five regional water groups will deliver their first plans in September 2023 and water companies' individual WRMPs are then expected to align with the regional plans. The national framework sets out the expectation that regional groups and water companies will deliver increased resilience to a 1 in 500 year drought through ambitious demand management, reducing leakage, and development of new infrastructure to increase water supply; such as reservoirs, water transfers, desalination, and water reuse schemes.

Key findings:

- The sharing of water resources across company boundaries has the potential to enhance resilience at a lower cost than siloed interventions.[192] The case for enhanced resilience was made through modelling and cost-benefit analysis to demonstrate the benefits of resilience to an extreme drought, rather than relying on emergency supplies.[193] Regional water groups are expected to identify a range of options to balance future water supply and demand, and this approach is reviewed every 5 years as a form of adaptive management.
- Alongside the national framework, a team of people from the water regulators Ofwat, EA and DWI have come together to develop the Regulators' Alliance for Progressing Infrastructure Development (RAPID).[194] The collaboration aims to provide a responsive and supportive regulatory environment to progress nationally significant water infrastructure projects. This includes water transfer schemes across water company boundaries and development of joint water infrastructure. RAPID aims to identify opportunities, barriers and gaps in order to develop regulatory frameworks so that the water industry has "construction ready" projects by 2025. By joining up, the regulators can work more effectively to address issues and safeguard water. For example, whilst Ofwat has suggested water transfers can be an economical approach, the DWI must ensure that public health is protected and that risks to drinking water quality are managed, and the EA must ensure security of supply as well as environmental protection. RAPID's joined up approach allows these objectives to be balanced and concerns resolved collaboratively with the overall aim of enhancing water resilience and

the environment.

- The National Infrastrucutre Commission recommended the regulatory framework needs to be updated to facilitate long term investment, including removing strategic investments from price reviews.[195] Ofwat's new process of direct procurement for customers (DPC) establishes a way for water companies to competitively tender significant infrastructure projects, allowing scope for greater innovation and commercial benefits. DPC has the potential to be used widely for future schemes.[196]
- Regional groups are adopting different approaches in preparing regional plans. Water Resources South East (WRSE) are developing a multi-sector, regional resilience plan for the South East.[197] The approach widens the focus by considering resilience to droughts and a range of unknown and unplanned shocks. The resilience of public water services will also be considered as part of the bigger picture– in terms of its impact on the resilience of other related and connected systems: non-public water supply, the environment, and the wider South East society and economy. WRSE have developed a resilience framework for assessing their portfolio of options, scoring resilience against a range of attributes which enhance three aspects of resilience: reliability, adaptability, and evolvability.[198]
- Water Resources East (WRE) have adopted Integrated Water Resource Management (IWRM) as central to their approach, promoting the coordinated development and management of water, land, and related resources, to maximise economic and social prosperity in an equitable manner without compromising the sustainability of ecosystems.[199] WRE uses a combination of decision making under uncertainty (DMUU) methods to account for many factors including climate change and growth. WRE aim to co-create solutions and build a long-term, multi-sector adaptive plan with stakeholders including farmers, land managers, councils and power generators.[200]

Examples of good practice and areas for improvement	
Anticipate	– Evidenced-based **analysis and forecasting** demonstrated future deficit scenarios in water supplies, and through the national framework **new capabilities were developed** to model droughts and water scarcity at a national scale – The national framework has developed a **common understanding of expectations** across stakeholders and aims to achieve a **standard of resilience** to a 1 in 500 year drought – **Demand management** is as a central part of the twin-track approach to achieve long-term water resilience – **Coordinated design and planning** is achieved by integrating the needs of water companies with farmers, industry, power companies and the environment, developing a holistic portfolio of options which are flexible depending on future conditions.[201] The national framework also established a common set of baseline scenarios for the regions to plan against.
Resist	– By **proactively taking pre-emptive action** to enhance supply and manage demand, water companies aim to **prevent** water shortages in future
Absorb	– Water transfers and sharing water resources via **interconnected networks** strengthens companies' ability to manage supply and demand and mitigate the impacts of drought – **Diversity in supply sources** – such as reservoirs, water reuse, desalination, and water transfers strengthen drought resilience, particularly sources that don't rely on rainfall – **Increasing capacity** of the water supply helps to mitigate against drought

Examples of good practice and areas for improvement	
Recover	– The regional plans recognise **rehabilitation of ecosystems** is central to achieving long term resilience, committing to reduce abstraction from sensitive environments and compensate with other supply measures[202]
Adapt & transform	– **Options are kept open** and uncertainty is managed through adaptive planning and decision making under uncertainty (DMUU) methods employed by regional water resource groups – **Options can be trialled and tailored** before scaling up, and can involve **collaborative action** between water companies and other major water users – **Good practice is shared** by regional water groups, and via publication of the national framework for water resources[203] and regional water plans – RAPID's cross-regulator alliance is an i**nnovation in regulatory approach**, allowing opportunities and trade-offs to be considered in parallel, and speeding up issue resolution, decision making, and potentially regulatory reform.

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