Draft Water Resources Management Plan 2019

Technical Report - Water supply resilience

Draft WRMP19 Technical Report – Water supply resilience

Contents

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1. Overview

This technical report details how United Utilities has identified appropriate water supply resilience considerations for inclusion within the 2019 Water Resources Management Plan (WRMP19).

The Defra Guiding principles and Environment Agency (EA) Water Resources Planning Guideline[1] ('Guideline') stipulate a number of aspects of resilience that need to be considered within the plan. How these have been incorporated within the plan is described within this report.

> *"To assess the resilience of your supplies, we expect more thorough testing of vulnerability of water supply systems - not solely tests based on historic events but future events that could reasonably be foreseen – to enable you to better plan for, and respond flexibly to future uncertainties. You should also assess resilience to other hazards such as flooding and freeze-thaw impacts and the overall resilience of your network. Where appropriate, you should include options to improve your resilience in your plan." – Defra Guiding principles*

Resilience has been defined as "*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*" via the UKWIR project report "Resilience Planning: Good Practice Guide - 13/RG/06/2" and has been endorsed by Ofwat through the Resilience Task and Finish Group report and has thus become the industry standard definition.

The above UKWIR report includes a reasonably comprehensive identification of potential hazards that could affect water supply resilience. The key hazards that exhibit the highest risks to our supply system have been selected from the fuller list for further review; the remaining hazards would only be considered on a case by case basis where a particular asset is known to have exposure to the hazard. This selection of key hazards has been achieved through a review workshop considering historical incidents, near misses and investments that have been made or considered to manage significant resilience risks. Some of these selected hazards have been considered at a system level and some against individual assets, depending upon the expected scope of the hazard.

In the context of the WRMP we have taken the following key steps to incorporating water supply resilience into our thinking:

1. Consideration of the effects of a **severe drought** upon our ability to maintain adequate water supplies. As an extension of the traditional 'dry year' WRMP assessment, this is detailed in the Sections 4.4.8 and 6.3.1 of the *Draft Water Resources Management Plan 2019,* with further detail in *Draft WRMP19 Supply forecasting – Technical Report'*;
2. Consideration of the effects of a **severe freeze-thaw** upon our ability to maintain adequate water supplies (Section 4.3.1 of this document);
3. Identification of any water resources options that we are considering to reduce the risk of water supply failure risk associated with other resilience hazards, as assessed through our Wholesale Risk and Asset Planning (WRAP) Process[2]; including flooding, power and critical asset failures (Section 6); and
4. Tested our preferred WRMP plan for wider resilience benefits, specifically in the context of the peak demands associated with a major freeze-thaw event (Section 7).

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[1] The Water Resources Planning Guideline (April 2017) has been referenced when writing this report

[2] WRAP is our company wide asset management process to identify risks and issues, identify and monitor strategic performance requirements, and prioritise risks and issues for investment or operational management.

The identification of resilience risks and the prioritisation of options to manage these risks is an ongoing element of our WRAP process and has not been included within the scope of previous WRMPs. This means that in this plan we report the results of our risk assessments, and identify potential solutions to our biggest risks. For the future, we are working to define a programme of resilience investment to be delivered at a pace customers support and can afford.

We believe that our approach has provided a robust assessment of our water supply system's resilience to a range of credible hazards, which is significantly wider than traditional water resources considerations included within previous WRMPs as outlined in the Defra Guiding principles. This has led to a more fulsome identification of shocks and stresses that can present risks to our water supply system and will lead to a lower risk of service failure to the customers we serve than the traditional WRMP approach.

2. Scope of report

This report provides some technical detail to describe our approach to incorporating wider water service resilience risks into our Draft Water Resources Management Plan (Draft WRMP19) as distinct from the traditional dry year assessments. We describe the process that we have followed to identify our current baseline risks associated with a key set of priority hazards. We then describe the process for option identification and selection. We are still in the process of completing the option identification and selection process for addressing priority resilience risks at the time of issuing the Draft WRMP19, because this requires further customer research and consultation. Other resilience risks will be considered as part of our ongoing business-as-usual prioritisation of investment.

Two "all system" approaches have been delivered for assessing water supply resilience to extreme drought and to freeze-thaw. The results of the specific resilience system modelling studies into extreme drought are provided in a separate technical report[3], and summarised in the main report as described earlier. The summary results and approach for the freeze-thaw assessment are included within this report. These results demonstrate the baseline and forecast interruption risk profile under key resilience shock conditions. The resilience risks and associated options are identified through our Wholesale Risk and Asset Planning (WRAP) Process, and prioritised for investment over time as part our business planning processes. The largest and most significant water service resilience risk, known as "Manchester and Pennines resilience" (M&PR) is associated with a potential failure of a major strategic aqueduct. This has been subjected to a detailed risk assessment process and is currently undergoing a comprehensive option selection and appraisal process described in the main WRMP document and this technical report.

In addition, we are actively evaluating potential programmes of work for 2020-45 associated with our strategic aqueduct system, and certain critical water treatment works and trunk mains that could impact upon our water resources balance. This would typically be through improved reliability affecting our outage position over time, but also through some additional resource development, see Table 1, where this is the most effective balance between risk reduction and bill affordability. This programme would target a significant reduction in the water supply interruption risk for many of our customers.

The preferred WRMP19 options have been tested for their impact upon resilience through a consideration of their impact upon the extreme demand conditions observed during a company-wide

[3] *Draft WRMP19 Supply forecasting – Technical Report'* for position of drought risk, plus *Draft WRMP19 Options Appraisal – Technical Report'* for consideration as part of options appraisal and stress testing of the plan.

freeze-thaw event. This was carried out through the same system modelling approach as for the baseline freeze-thaw assessment, an approach detailed later in this report.

3. Overview of methodology

Figure 1 below summarises the approach that we took to identifying and assessing water service resilience through the reduction of the risk of customers of a reliable, wholesome water supply. We have used a range of techniques to identify specific resilience risks and associated options to resolve them. The approach for the assessment and relative ranking of resilience risks and their associated options is also described.

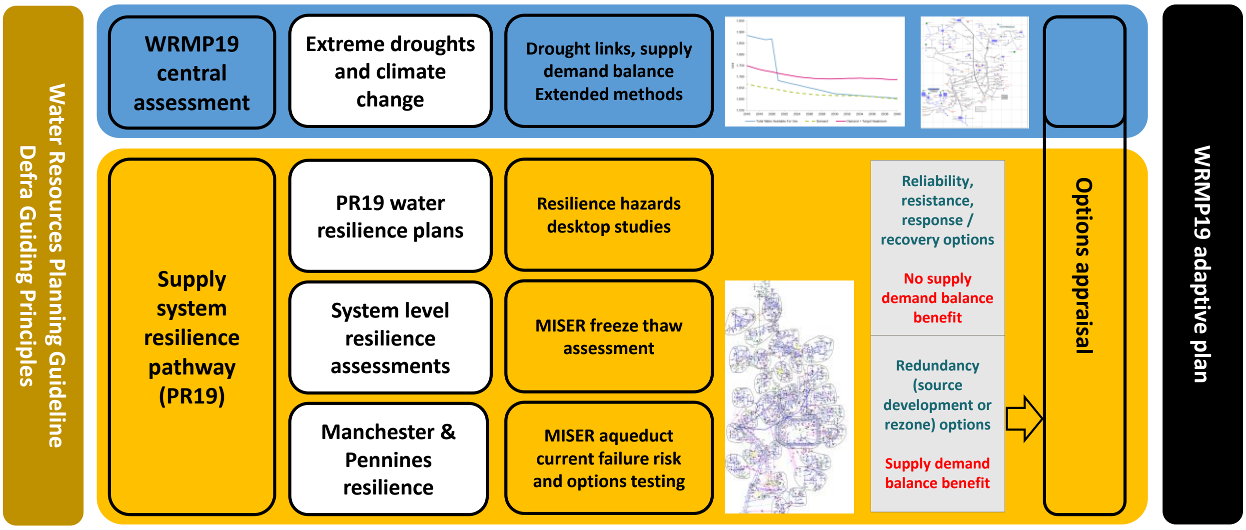

Figure 1 High level schematic of WRMP resilience methodology demonstrating how resilience risks and benefits are assessed.

4. Resilience risks identification

The identification of resilience risks for inclusion within the WRMP and wider business planning processes was through a number of different techniques, these are briefly described below.

4.1 Hydraulic network assessments

These studies were based upon hydraulic models and were focussed around individual Water Treatment Works (WTW) and their associated water supply zones. Each study identified potential shortfalls in the current ability to supply customers in the event of a long duration [4]outage of a WTW. Each study included a review of engineering options to provide alternative supplies from a different source to the customers at risk of losing supply. Some of these study options have been delivered during the current investment period 2015-20 and others will be prioritised for delivery during the coming periods 2020-45. The nature of resilience solutions means that they alleviate constraints at a local water supply zone level rather than a water resources strategic level relevant to dry year assessment in the WRMP, however, we will consider where any asset interventions influence the supply-demand balance at each WRMP planning cycle. These studies can be used to model the

[4] The studies considered WTW outages of three different durations: less than 12 hours, 5 days and greater than 5 days.

consequences of a wide variety of different resilience hazards upon a local element of the supply network; such as, flooding, power or critical asset failure.

4.2 All hazard resilience workshops

These workshops are essentially a source to tap asset review and have been used to identify a wider range of vulnerable assets than the hydraulic network assessments such as service reservoirs, pumping stations and trunk mains. Examples of the types of risks that have been identified through these workshops were pollution events in rivers or reservoirs or potential catastrophic raw water asset failures.

The risk assessment process gives a structured way to quantify risks associated with resilience hazards that are both shocks and stresses. Resilience shocks are relatively short duration events that provide extreme demands upon a system, most of the key hazards that we have reviewed could be classified as resilience shocks. Resilience stresses are hazards associated with a more gradual change in context that typically erodes the capacity of a system to manage shocks. Consequently, the assessment of resilience stresses would typically be alongside shocks. The most significant example of a stress clearly relevant to the water service is drought. Droughts can effect service on their own, but clearly also reduce the capacity of a system to respond to any other shock event, such as a critical asset failure.

Whilst these reviews have been focused upon the identification of resilience risks, rather than solutions, inevitably some risks have solutions that may have been previously identified through other bottom up risk processes or through the WRMP19 options review. Examples of additional sources that may be considered for development to meet long-term water supply resilience objectives rather than dry supply-demand considerations include:

Table 1 Example water resource options for water supply resilience

WR Option ID	Description
WR120	New boreholes at treated water storage (Wirral), new 15 Ml/d WTW, revocation of existing abstraction licences at Gorston, Springhill and Hooton
WR047b	New abstraction from the outfall of the Milwr tunnel at Bagillt, new c.18km raw water transfer main, new raw water pumping main to inlet of Sutton Hall WTW
WR117	Increased abstraction from the Ribble Carboniferous aquifers, treatment to potable standards and transfer to treated water storage in SRZ
WR102a	Reinstate abstraction from 11 Widnes boreholes, reinstate Cronton Booster, new raw water main to Prescot WTW, modified WTW process for additional 52.3 Ml/d.
WR105a	Decommission existing Lymm WTW, utilise both existing boreholes at Lymm at 9.1 Ml/d, convert treated water main to raw water main to new WTW located at Sow Brook (near Lymm), utilise existing treated water main to Manchester DMZ.
WR107	Reinstate Aughton Park and Moss End boreholes (Bickerstaffe) at 10 Ml/d, new raw water main to existing Royal Oak WTW, modified WTW to allow for additional volume

The workshops were focussed in each of the company's 33 Demand Management Zones (DMZ) and included a facilitator, the Asset Manager and typically a Production Manager and appropriate network resources. The focus of the workshops was to evaluate any known single point of failure or other significant perceived resilience risk. Approximately 100 individual resilience risks were identified through the workshops, there was a substantial overlap with the hydraulic assessments in the identified risks. Each WTW identified via the hydraulic assessment was also identified via the all hazard workshops, however further non-WTW risks were recorded. The output from these workshops became the basis for our register of "single point of failure" resilience risks.

The UKWIR report 13/RG/06/2 defines an "all hazards" approach to resilience assessment. The general approach is to consider appropriate hazards that may result in a service failure, in this case customer supply interruption. We evaluated the full list of hazards identified through the UKWIR report in an internal workshop to generate a targeted, more focused list for general resilience assessments. The approach taken was to review each hazard and to consider whether this hazard had ever materialised within either our company or the wider UK water industry, or was deemed credible in our system. This enabled us to identify the primary hazards that contribute most significantly to water supply risk. The hazards considered for water service supply service failure risks are described below. These were evaluated in addition to the systems approach for freeze-thaw and drought, see Section 4.3.

Table 2 Water service resilience hazards assessed

Hazard	Description
Power outage	This is modelling the impact of losing power to a facility from a third party supply, this may be due to any root cause. This failure mode is not for failure of our assets on site, but failure of the external power input. Only assess this failure mode for powered assets or where power failure may lead to loss of supply.
Fire	This is looking at the risk of a fire on site. This risk is primarily associated with High Voltage (HV) assets and is modelled specifically against HV transformers.
Critical asset failure	Critical asset failure is included for civil, M&E (mechanical and electrical), ICA (instrumentation, control and automation) as well as infrastructure assets such as mains and aqueducts. This is primarily used where the failure of a single critical asset could lead to the loss of supply or loss of treatment. Many resilience needs can be assessed primarily against this failure mode.
Flood	This models the potential for flooding based upon EA fluvial and coastal flood modelling zones.
Malicious damage	This models the expected risk from 3rd party malicious damage, historically this work has largely been considered under the Security and Emergency Measures Directive (SEMD) programme.
Contamination	Source contamination or infiltration of contaminants into the water process or network. Typically this will include for river contamination, impounding reservoir algal blooms and service reservoir infiltration.
Human factors failure	Any potential failure that is associated with a non-asset related issue. Typical examples could include a failure to calibrate or verify the operation of an instrument, a chemical delivery to the incorrect tank, running processes in manual rather than auto or general changes to a system or process carried out in a way that leads to the system failure. This failure mode should always be included for resilience needs.
Cyber failure	Any potential supply failure associated with the failure of a telemetry or control or monitoring signal. This failure mode should be included for all resilience needs where telemetry is available for the assets associated with the need.

Resilience risks identified from the existing WRAP process were screened to identify those which could have a material effect upon the supply-demand balance; principally those that may lead to the development of new sources and those which may lead to the capability to move existing water supplies in strategically significant ways and therefore have additional benefits to the supply-demand balance in times of water stress. The preferred options to resolve these risks were then compared to the unconstrained WRMP19 options list and it was confirmed that they were included for assessment under the core WRMP19 options identification process.

Resilience risks identified through workshops, facilitated by Arup Engineering, focused around each of the current 33 Demand Management Zones (DMZs) and involved the appropriate asset managers and various operational managers with familiarity of the DMZ. Operational response and recovery capability was included in the risk identification process primarily by excluding risks where a network rezone or water tankers could ensure the ongoing provision of a safe water supply to all customers who would otherwise be affected.

A total of approximately 100 resilience risks were identified through this process across all 33 DMZs. This list has been continually reviewed and updated as the delivery of additional interventions has helped to reduce either the probability, expected duration or credible consequence of the inherit risk.

The assessment of the resilience risks has been through a standardised methodology to ensure consistency in their ranking and subsequent prioritisation.

4.3 System level testing

We carried out system wide assessments of the ability of the network to respond to extreme demand scenarios. The particular scenarios tested included relatively short duration shocks such as a freeze-thaw event, where demand would be unusually high due to high volumes of bursts and hence leakage and also longer duration stresses such as an extreme drought where water resources would be very constrained and demand is typically higher. This was particularly specified in the Defra Guiding principles.

4.3.1 Freeze-thaw

Peak demand deficits due to freeze-thaw events have been considered. As this is a fairly short duration event that can have very local effects, the existing AQUATOR model used throughout the WRMP19 planning process (to assess dry year 'stress'), with a monthly demand profile, was considered to be inappropriate to demonstrate the current and future risk associated with short duration freeze-thaw "shock" events. A different modelling tool, MISER, was used for this assessment, this was largely because of the greater resolution of the supply system as represented in the business as usual MISER model.

For the freeze-thaw assessment a suite of simulations was carried out utilising the most severe historical freeze-thaw demand profile with data available, from the winter of 2010/11. The winter of 2010/11 included three separate freeze-thaw events, each was modelled using daily timesteps and the latest available MISER model configured to represent all three potable resource zones[5] at the expected 2022 configuration (i.e. with the Thirlmere transfer in place). The specific updates to the model that reflect changes from the previous network configuration at the date of the simulation (summer 2017) are primarily the following:

- Various maintenance projects that are due to have the effect of restoring peak production capacity at a number of WTWs including for example Oswestry and Franklaw WTW;
- The completion of the Southport projects designed to ensure sufficient peak capacity during summer months, including the completion of the Royal Oak WTW; and
- The completion of the Thirlmere transfer project that brings West Cumbria into the Strategic Zone with the completion of the new WTW.

For each of the events five demand scenarios were simulated, equating to the historic peak demand, and four incremental uplifts each of 5%. Deficits for each timestep in each DMZ were identified and recorded. It should be noted that the MISER model doesn't include local storage so that the effect of short duration or relatively small deficits in the model can usually operationally be managed with existing service reservoir storage.

[5] The fourth small non-potable Barepot water resource zone is covered in the assessment process but has not currently been identified as containing priority water service resilience risks.

4.3.2 Extreme drought

Please see *Draft WRMP19 Supply forecasting – Technical Report* for explanation of work to develop severe and extreme drought scenarios, and results from testing of risk in this area. The *Draft WRMP19 Options Appraisal – Technical Report* explains how options appraisal and stress testing of the plan has included severe and extreme drought resilience as an integral component of decision-making.

4.4 Interruption risk studies

These studies used the mass balance representation of the supply system held within MISER to enable credible failures and constraints to be modelled to understand the current and future risk profiles, with and without mitigation options. Studies have been carried out to identify the effect of specific, large scale changes or events to the supply system. An example of one of these studies was the impact upon water trading to the supply resilience of the network and also the potential failure of assets associated with the Manchester and Pennines Resilience risk, the single most significant water service resilience risk identified to date.

We have used the same models to help to demonstrate that the introduction of the most credible expected water trades should not introduce additional, unacceptable risk to our customer's water supply. This was demonstrated through the assessment of any demand deficits associated with the network including potential trades and the requisite enabling works as described in Section 7.

4.5 Reservoir risk assessment

We own a large number of dams and reservoirs, and a key priority is managing the associated risks in line with Health and Safety Executive guidance. We have a well embedded risk assessment process and supporting systems to evaluate, track and manage the societal risks associated with these assets. The primary focus of our investment programmes across the next 25 years will be to reduce the risk that people and infrastructure in the North West are exposed to from our fleet of reservoirs. We are committed to a long-term programme of risk reduction.

We are focussed on reducing the risk of dam failure, an event which would cause great damage and distress to people and major cost to our business. Our future programmes of work are aimed at reducing the risk of a catastrophic incident and improving our source reliability. We are making our reservoirs and dams more resilient to hazards such as extreme flood events through improving reservoir capacity as well as reducing the risk of failure by erosion with other measures.

5. Customer research summary

The key elements of customer research that we have used to inform our approach to managing our water service resilience can be summarised in the following questions:

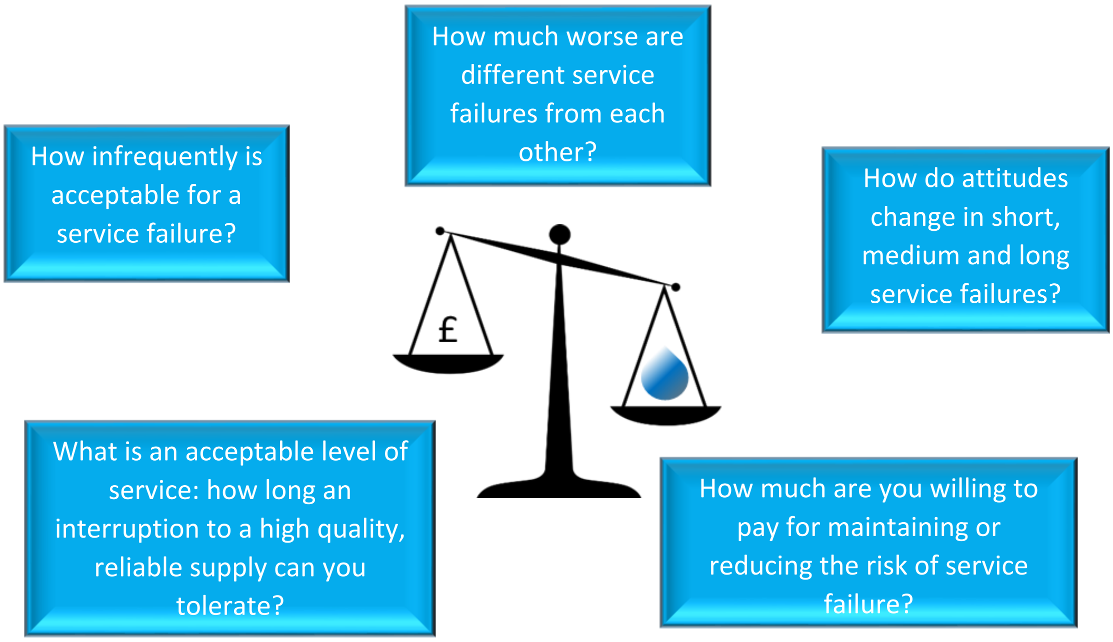

Figure 2 Key water service resilience questions

The customer research and approach to evaluating the responses to these questions is described more fully in *Draft WRMP19 Technical Report – Customer and stakeholder engagement* (Section 4). The overall value for avoiding a long term interruption has been assessed as £290/day. The relative weightings for different types of service failure were assessed from research carried out with customers affected by our major water quality incident in the Fylde area during 2015.

Table 3 Water service relative impacts

Customer impact	Relative Weighting
No water – service interruption	1.0 (default)
Discoloured water (safe to drink)	0.6
Taste or odour issues (safe to drink)	0.6
Boil water notice	0.35
Do not drink	0.8
Do not use	1.0

As previously stated, using our customer research we have evaluated relative weights for different types of service interruption. These are generally assessed as interruption risks, but in the case of the Manchester and Pennines Resilience project, where a more comprehensive assessment of potential impacts has been carried out we have used specific weightings for water quality service risks in any failure mode where these could be expected.

6. Resilience option assessment

All resilience options were assessed by either their expected impact upon the risk of interruption to supply or their potential to lead to a water quality incident. In some cases the interruption would be due to poor water quality, rather than loss of supply directly. We have chosen to assess both of these outcomes against a common metric of interruptions of service. Where it has been possible to identify the expected outcome and differentiate between a water quality or interruption consequence we have converted water quality consequences to "equivalent interruption days" with the weightings as outlined in Table 3.

There were two different approaches to the assessment; a desktop version where no system model is available that can reflect the risk, and a system model. In each case the output is comparable and is defined as an annualised risk of interruption. The system model has been used extensively in the assessment of the Manchester and Pennines Resilience project risks and options.

6.1 Options identification and appraisal

6.1.1 Overall approach

All resilience risks had option assessment carried out through the WRAP. The process was varied for different priority risks with those which were assessed to be the most complex and highest priority getting the most in-depth option and costing assessments.

A series of network contingency models and associated option identification reports was commissioned for each water treatment works to document a current view of required network activities in the event of long term failure of the works. This led to the confirmation of resilience risks associated with specific water treatment works failures. This work has also formed the basis of cost and scope estimates for options to address some of the identified resilience risks.

The identification of options to manage resilience risks is typically managed through our standard WRAP. Central to the WRAP process is a series of "risk and value" gateways where the need and potential options are challenged by our strategy and engineering teams.

Prior to each gateway we consider a full range of potential options we can use to manage the risk. We ensure that we have covered all credible options by reviewing the risk against our Generic High Level Solutions (GHLS), see Table 4 below. This challenges us to think about all potential risk management approaches and to consider ways to manage the risk without a "new build" solution.

Table 4 WRAP Generic High Level Solutions

Generic High Level Solution (GHLS):			Resilience 4 R's
1	**Monitor and Respond**	Accept the risk and plan to respond in an agreed way if the risk arises with a contingency plan	Response and Recovery
2	**Operational Intervention**	Return relevant assets to their original performance through one off maintenance, coupled with an agreed contingency plan	Reliability
3	**Optimisation**	Improve relevant asset performance by changing operational and maintenance regimes, possibly coupled with one off investment to increase the capability of the existing assets	Reliability
4	**Refurbishment**	Capital investment on relevant assets to prolong asset life and restore their performance to the original design	Reliability

5(a)	**Replacement**	Replace the relevant assets on a like for like basis where refurbishment is unlikely to be economically viable	Resistance, Reliability
5(b)	**New Asset**	Capital investment on new or additional assets to meet new performance standards, enhanced reliability or a more cost beneficial solution	Resistance, Reliability, Redundancy
6	**Partnership**	Collaborative investment shared or wholly provided through a third party with costs and benefits shared across all parties	Any of 4 R's

This process has been externally audited as a robust methodology by Arcadis Consulting.

6.1.2 Options identification and appraisal – Manchester and Pennine resilience

For the M&PR risk we have developed a similar process, but more specifically tailored to the complex interaction of resilience risks. The long distance water transmission pipelines that supply Manchester have been the subject of investigation and refurbishment since the 1990s. Considerable planning and investment in enabling works was required to undertake two outages of one of our major strategic aqueducts supplying Manchester, a 109 km pipeline commissioned in the 1950s. The findings of the second outage, completed in the winter of 2016, indicate that there are both water quality risks and water supply risks. These risks have been assessed as the highest ranked water supply resilience risks when assessed in accordance with the company resilience risk assessment process.

Key failure modes were identified to represent the greatest resilience risks, and probability and consequence was determined for each failure mode. We developed multiple options to reduce the resilience risk to an acceptable level. This process follows the cabinet office guidance for the four Rs of resilience; aiming to offer solutions across the four Rs.

Additionally, we are undertaking operational interventions and optimisation through:

- On-line monitoring and enhanced laboratory analysis of water samples;
- Installation of rapid-response ultraviolet treatment units for biological contamination;
- Automated facilities that divert short term deterioration of water quality to waste;
- Agricultural land management to reduce pathogens entering water supplies; and
- Assessment of additional supply, re-zone and alternative water supplies.

We have also already committed a project to address the highest risk tunnel section of the aqueduct system.

We are currently undertaking customer research to understand the level of support for further risk mitigation to improve the resilience of the aqueduct system. The five alternative solutions that we have selected for consultation and customer research are shown in Section 6.4.4 of the Draft WRMP19 main report. The process for identifying options and solutions to manage the risk is described in more detail in the appendix to this technical report.

6.1.3 Reservoir Resilience Programme

Our reservoir investment programmes are delivering improved reliability through more proactive interventions. By being proactive we are able to improve scheduling and carry out work at lower risk times. Much of the industry operates a reactive approach to safety concerns, leading to unplanned emptying of reservoirs to take them out of service. It is typical that an affected reservoir is operated with major constraints upon yield for up to a year whilst investigations and any remedial work is carried out.

By proactively carrying out risk reduction interventions (such as improving flood capacity, or installing filters to prevent internal erosion) the period out of service can be planned to avoid interruptions, and with the work programmed and scheduled to be efficient and timely. Proactive risk reduction is safer for downstream communities than 'fix on fail', and less likely to lead to supply interruptions for customers.

The risk reduction measures we are undertaking often involve increasing the capacity of the dam to resist floods, ice loading, or earth movement, making the supplies to customers more resistant to interruption in the event of a challenging incident.

By reducing the probability of dam failure we are also protecting the property and infrastructure that lies downstream of our dams (including homes, schools, hospitals, and transport and utilities infrastructure), preventing the damage to that infrastructure that would occur in the event of a dam failure. Whilst people could be evacuated in the event of a slowly developing dam failure, built infrastructure could not be relocated and the disruption to normal life and the economy that loss of infrastructure causes cannot be over stated. Reducing the risk of dam failure is therefore improving the resilience of the entire community, not just for those living immediately downstream of the dams.

7. Testing the preferred plan

The preferred plan, including options to facilitate a potential water trade has been evaluated to ensure that there is no deterioration to the overall water supply system resilience. The approach taken for this test was to utilise the previously developed MISER "all system" model that was used to test the supply system against extreme freeze-thaw events.

The selected enabling works for a water trade were defined and modelled within the MISER model. The principal changes were the inclusion of the additional sources or reduced demand, plus some reconfiguration of strategic trunk mains in the south-west part of our region.

The model was then run with the same extreme freeze-thaw demand profiles previously utilised for modelling the baseline risk of the system against this hazard. This equates to simulating each of the three historic freeze-thaw events during the winter of 2010-11 five times at 5% increments of increasing demand. A total of 15 simulations were therefore produced to test the plan.

The results of the extreme demand analysis test against the proposed plan show no deterioration against the baseline risk. The first deficits appear when the demand is increased by 15% against the observed historic maximums in the two most stressed demand management zones. This is a high percentage increase relative to these historic maximum.

8. Water supply resilience plan

We are planning to continue to reduce the largest identified water service risk during the upcoming investment period from 2020-2025 at a pace and to a level supported by our customers and other stakeholders. This relates to Manchester and Pennines resilience as aforementioned.

The options being considered comprise either rebuilding or repairing aqueduct sections, new water treatment works for operational use, or some new assets to provide redundancy for outages or failures. At this stage we have assumed that there is no material impact of these options on the supply-demand balance position, noting that these are being defined to address a different resilience driver. Once the options to address this risk have been further established we will be able to examine how this interacts with other elements of the preferred plan and whether there are any resulting changes to the final supply-demand balance position. We therefore aim to incorporate this element further into the final plan following consultation, if necessary. However, it should be noted that this is not expected to impact on the water trading options covered in the next section (Alternative Plan 4); these options are designed to protect customers and the environment from the impacts of water trading from a defined base position.

9. Conclusions

The preferred plan has been tested against the credible, stretching, demand scenarios that simulate a range of extreme system wide freeze-thaw events. The preferred plan shows no deterioration in water supply resilience in any tested scenario. The strategic choice for water service resilience is to continue to reduce the Manchester and Pennines Resilience risk during the investment period 2020-25 is being consulted upon with customers and other stakeholders to understand wider views on the level and pace of risk reduction.

10. References

Department for Environment, Food and Rural Affairs, 2016. Guiding principles for water resources planning.

Environment Agency and Natural Resources Wales, 2017. *Water Resources Planning Guideline: Interim update.*

UKWIR, 2013. Resilience Planning: Good Practice Guide [13/RG/06/2].

Appendix – Manchester and Pennines Resilience Options Process

A.1 Overview

Our largest and most significant water service resilience risk, known as "Manchester and Pennines resilience" (M&PR) is associated with a potential failure of a major strategic aqueduct. This has been subjected to a detailed risk assessment process and is currently undergoing a comprehensive option selection and appraisal process. This appendix describes the risk assessment and options appraisal process

A.2 Understanding the risk

The aqueduct in question has been subject to inspection in 2013 and 2016. During these inspections a range of data was collected. We further investigated the system risk and resilience by three key elements. They consist of:

1. A condition assessment model for the aqueduct.
2. Assessment of the consequences of failure, both for water quality and loss of supply.
3. A system risk curve, identifying all relevant failure modes with an assessment of probability and consequence.

A failure mode describes the specific manner or way by which a failure occurs in terms of failure of part of a defined system under investigation. In this assessment, failures modes are the ways or means that the aqueduct, or associated assets, can fail resulting in a negative impact on customers leading to loss of supply or changes in the quality of the water supplied. There may also be other societal consequences such as flood damage.

We undertook an assessment of the aqueduct as a linear supply system using information gathered during the 2013 and 2016 outage investigations to develop a comprehensive list of potential failure modes. Failure modes fall into two prime consequence categories: water quality and loss of supply. Initial identification gave circa 60 failure modes to be assessed; this was reduced to 17 by combining section failures with a common or similar consequence and removing any duplication in hazards, assets and consequences, etc. This included removing any modes that incorporated double jeopardy where this results in significantly reduced likelihood of the consequence materialising.

Our regional supply network is a complex and highly integrated system. Different failures of different assets which make up the system will have varying impacts on water supply depending on the prevailing conditions in the system. Demand, raw water availability and asset capabilities all vary over time. In order to fully understand the system risk envelope, we have undertaken detailed supply demand modelling to consider the different events and their impacts.

To quantify the security of supply risk, we have adopted our existing production planning mass balance model, MISER as the basis of our assessment approach. The existing model contains all Water Treatment Works (WTWs), large diameter trunk mains (LDTMs) and strategic service reservoirs. We have extended the MISER model to account for upstream hydrological constraints that may be impacted from longer duration failure events. We have for the first time, combined both our water resources "Aquator" and production planning tools to use MISER in this way.

For the purposes of Manchester and Pennines Resilience, we commissioned Servelec Technologies who have a proven track record in carrying out complex modelling analyses in the water industry, to work with us on the consolidation of our MISER model and its use in the assessment of security of supply risk.

The impact of each of the failure mechanisms has been tested under four potential scenarios:

Failure Occurrence Conditions	Starting in April	Starting in October
Normal Year	Normal year demands Normal year hydrology applied (1978/79)	Normal year demands Normal year hydrology applied (1978/79)
Dry Year	Dry year demands Dry year hydrology applied (1995/96)	Dry year demands Dry year hydrology applied (1995/96)

Normal and dry years account for the variation in both demand and hydrological conditions under a normal and dry year. A failure occurring in April and lasting 6 months captures the impact on our supply system during the summer demands. Similarly, a failure during October and lasting 6 months takes account of winter freeze-thaw events.

For coherence, the underlying conditions and assumptions used in the MISER model have been aligned with our Water Resource Management Plans (WRMPs) which is appropriate for the purposes of Manchester and Pennines Resilience.

Because failure events are unpredictable and impacts are dependent on a range of factors such as the time of failure, the supply-demand position and water storage among others, we have accounted for a range of hydrological and demand conditions within our MISER model. These are summarised in the table below.

Criteria	Detail
Demand Data	District Meter Zone (DMZ) level weekly demand data Normal Year (Average) and Dry Year (Peak) demands applied Based on WRMP demand forecast
Leakage / Losses	Included within DMZ level demand figures Separate allocation of losses to our network of large diameter trunk mains
WTW Capacities	Consistent with WRMP supply assessment as the maximum sustainable capacity. Min, Max and initial business as usual starting flows apply
Raw Water Components (based on water resource's Aquator model)	**Raw Water Inflow sequences** – historic inflows into raw water impounding reservoirs (IRs) used
	Abstraction Licences – Annual (Ml/y) and Daily (Ml/d) raw water abstraction constraints apply
	IR Control Curves – our own constraints that ensure year round availability of raw water storage
	IR Capacities and Starting levels – Historic IR storage sequences used
	Emergency Storage – Accounts for c.20 days' supply and stops at assigned 'dead water level'
	Hands off flow (HoF) – minimal abstraction flows for river sources applied
	Compensation flows – Fixed Ml/d release requirements from our IRs
MISER Optimisation	Week by week – management of resource to meet demand on a week by week basis
Raw Water + Process Losses	Losses in raw water transfer mains up to the WTWs and losses as a result of the treatment process at the WTW are accounted for
Enabling Works	Account for network re-configurations we would need to undertake in the event of losing the aqueduct

In the case of catastrophic failure events leading to long duration outages of the aqueduct, we would operate under a set of conditions appropriate to these unique circumstances; these conditions would not form a part of our business as usual approach, but would be our 'emergency' response to such events.

Criteria	Assumptions Under Failure
Enabling	Strategic and emergency valves are made available in the model
WTW Capacity	WTWs ramp up linearly from their starting flows to available max capacity
MISER Optimisation	Week by week approach – this is how we would manage our supply system in the event of a failure
Raw Water	In an emergency, we would relax our IR control curves and make available our emergency storage Regulatory constraints and licences still apply (Abstraction licences, HoF and compensation flows)

A series of mass balance models (in MISER) of the supply system, have been produced for the above scenarios to enable credible failures and constraints to be modelled to understand the current consequences, in terms of demand deficits, both with and without mitigation options.

A deterioration model has been used to assess concrete lining deterioration in the potable water aqueduct. For the purposes of the deterioration model, a Hoek and Brown calculation has been used to determine a critical lining thickness after which further wear is assumed to present lining failure risk. The data used in the model was the tunnel construction method; concrete core sample strengths and depths of worn and unworn concrete; locations of water quality failures (exceedance over PCV) from sampled ingress during the outage and identified structural areas of concern recorded during both outages. The model produces a probability of failure for catastrophic liner failure due to wear, and consequent water quality or catastrophic structural failure and can be used to forecast the change in risk of catastrophic liner failure assuming that the liner continues to degrade at the average historic rate.

The results of all this analysis has been combined into an overall system risk curve. This is a common approach in the quantitative assessment of risk. It is usually shown as a plot of cumulative frequency or probability against consequences. In some fields the consequences are expressed as number of fatalities (N) and therefore the plot is commonly referred to as an “F-N curve”. However we have expressed the consequence in a common measure of “customer days lost” (the number of properties affected, multiplied by the number of days affected).

The system risk curve is a useful tool to understand how the risk arises from different parts of the system and we have used it to identify and select appropriate options to mitigate the risk. For the purposes of customer research and consultation we have simplified the system risk curve into three indicative events to represent the overall baseline system risk over a future 10 year period:

- 65% probability that 1.2 million properties could be affected by water quality problems for at least one week
- 35% probability that that 120,000 properties could be affected by supply interruptions for up to three months
- 10% probability that 240,000 properties could be affected by supply interruptions for up to two weeks

These represent the baseline risk in the absence of any options which are discussed in the following sections. It includes the impact of deterioration in the aqueduct condition from the outage into the 2020s, and works already planned to mitigate the current risk. The baseline risk ranks highly when assessed alongside other water assets in accordance with the company risk assessment process.

We have already committed a project to address the highest risk tunnel section of the aqueduct, and the benefits of this are included in the indicative events listed above. Options to further reduce the risk are considered in the following section.

A.3 Range of options considered

We have considered a broad and innovative range of intervention options to mitigate the resilience risk posed by the aqueduct system. This process began with the understanding of failure modes and risk described above. The system risk curve served to focus our attention on the wide range of potential options to address identified risks to customer supply. By identifying individual potential options, which could be later combined together to comprise overall solutions, we were able to remain open-minded and a broad list was developed rather than focussing in on a number of specific solutions.

The initial list of 396 options comprised both operational interventions such as increasing the outputs from existing Water Treatment Works (WTWs), and capital investment interventions which ranged from duplication of tunnelled sections of the aqueduct, through to construction of new water treatment works and demand management from multiple parts of our water supply network. The range of options proposed is shown in the table below and demonstrated through the subsequent sections.

Option category	Unconstrained options
Demand management	38
Distribution	118
Operational intervention and optimisation*	35
Quality	117
Resource	88
Total	396
*This includes a wide range of operational response / recovery options to allow us to respond effectively if the risk arises and return relevant assets to operation, coupled with an agreed contingency plan	

High-level costs for each of the initial options were subsequently estimated for comparison in order to determine the most cost-effective ones to take forward.

Following the initial identification and high-level costing of options, we continued the optioneering process in three major stages, as shown in Figure A1 below:

<u>Stage 1 (coarse option screening)</u>: We discounted options based on several factors such as estimated value for money, environmental impacts, technical feasibility (including water quality) and whether or not the risk reduction objectives were met. We reviewed each option to identify the extent to which that option benefits the environment or whether the environment suffers from the implementation of the option. Examples of options that have a positive impact on the environment include leakage reduction options (less leakage means reduced requirement to abstract and treat raw water). At this stage, we also considered whether the proposed option had the potential to impact on Special Areas of Conservation and/or Special Protection Area sites. These decisions were supported by calculations of the cost per megalitre for each of the different options to determine which would offer the best value for money for customers whilst comparing their relative geographical locations as well as assessing how applicable these options were in addressing the failure modes being identified. At this stage, the number of options had reduced from 396 to 244 options (*Figure A1*)

<u>Stage 2 (option grouping & coarse solution screening)</u>: The remaining options were then grouped together to form solutions, directly addressing each of the failure modes identified. At this stage, we grouped the number of options together into 78 solutions. This work was supported by an 'Option Solution Failure Design Tool'. This tool was used for recording and controlling the data associated with the grouping of options to solutions and failures mode. Once grouped together, an indicative overall cost for each solution was generated.

Following this, we undertook a secondary option screening process to discount options that had not yet been grouped into a solution.

The coarse solution screening considered the risk reduction (improvements in customer days lost) for each of the 78 solutions, against cost (Totex, NPV, bill impact) to inform the selection of the options taken forward to customer research.

Stage 3 (final solution screening): Following customer research, we will analyse the costs and benefits of the short-listed solutions and subsequently, determine our preferred solution. This will include customer preference for risk reduction and affordability, wider economic impacts, additional service benefits and the results of stakeholder consultation. This stage will be completed for the revised draft Water Resources Management Plan.

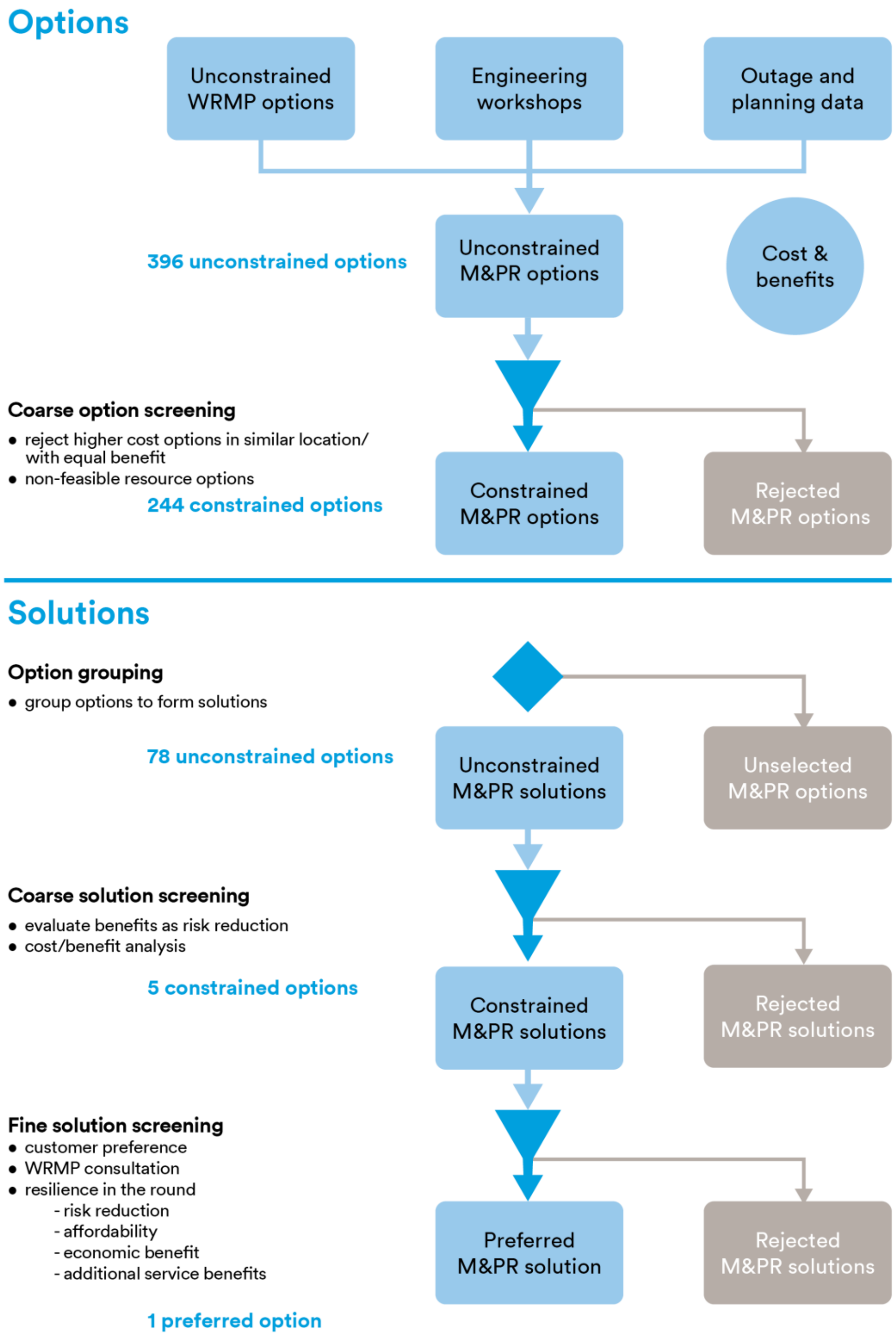

Figure A1 The Optioneering Process

The M&PR options have been developed in conjunction with the Water Resource Management Plan supply-demand options. Similar assumptions were used in developing and screening options, and the same document templates have been used. Relevant options from the WRMP19 supply demand 'pool' (i.e. those associated with the aqueduct and supplied areas) have been included in the M&PR options list.

Multiple benefits were achieved between both M&PR and the WRMP19 supply-demand options. These include the development of more robust options during the optioneering process, as these were developed from a multi-disciplinary and multi-driver approach. Knowledge sharing between the options sets was also undertaken during the optioneering process, to ensure that key factors were taken into consideration which would be useful for both the resilience driver and the supply demand driver.

We have focussed on the four R's of Resilience (*namely Resistance, Reliability, Redundancy* and *Response & Recovery*) throughout our optioneering process to propose options that span each of these four areas, to be considered. Figure A2 highlights examples of options considered under each 'R'.

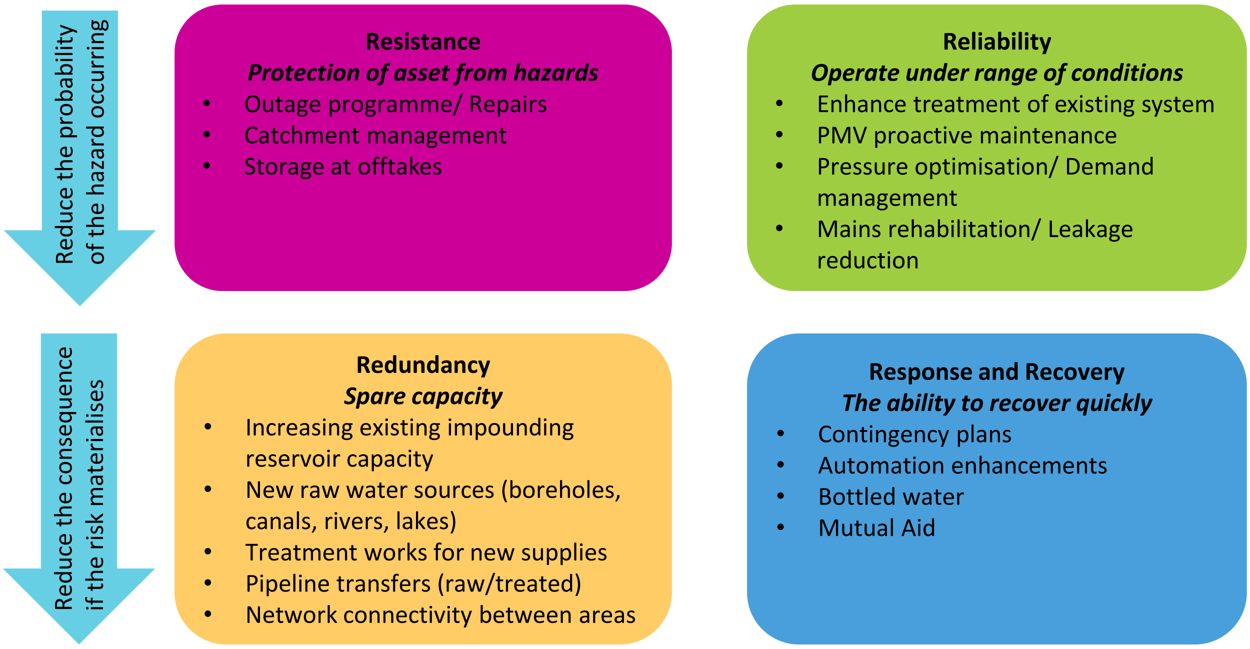

Figure A2 Demonstrating Resilience through Optioneering

Options considered ranged from a new treated water aqueduct, enhanced use of existing raw water sources, enhanced outputs from existing treatment works, new raw water sources and treatment works and enhanced use of existing and new network improvements. We also investigated the use of novel treatment technologies such as reverse osmosis. The range of options considered are summarised below:

<u>Enhanced use of existing raw water sources</u>

In order to improve overall resilience, we have considered increased abstraction from existing water sources. We have investigated a number of options, including relocating the treatment of the majority of Manchester's water supply from its current position in Cumbria, to a location just outside Greater Manchester. A key benefit of this is protection against potential ingress of contaminants into the aqueduct to ensure a consistent supply of clean drinking water to customers in Manchester and surrounding areas.

United Utilities has a number of existing abstraction licences, where raw water is taken from rivers and transported to a water treatment works for treatment, before being put into supply. In some cases, the actual abstraction rate is currently below the consented value. Work has been done to assess the feasibility of increased abstractions, hence increasing the availability of raw water for subsequent treatment and supply to customers.

Enhanced existing treatment works capabilities

We have also investigated options to improve the capability of existing treatment works. One such option is uprating the capacity of a water treatment works, which is not directly fed by the aqueduct. In order to do this, additional treatment is required and work has been done to assess whether this can be incorporated into the existing treatment works.

Another study which has been undertaken is looking to relocate some treatment units, from the current location on the outlet of a reservoir, to a nearby water treatment works. This reduces the likelihood of contamination and provides a more robust process for consistently providing clean drinking water. Other options which we have considered include reinstatement of an existing water treatment works that is not currently in use and carrying out improvement works on disinfection equipment, to reduce the chance of contamination entering into supply.

Enhanced use of existing network improvements

In order to improve overall resilience, we have developed a number of options that utilise the existing water supply network. A key benefit of these options is that they would minimise or eliminate the need to install new network or transfer pipelines, ensuring continuity of supply during an aqueduct outage.

In some options, uprating the flow from the West East Link Main (WELM) and Rivington was reviewed to avoid installation of new raw water pipelines.

A review of leakage reduction has been conducted in various District Metered Zones (DMZs) in order to minimise an amount of water loss. Reducing the level of leakage prevents the need to develop new water resources; thereby, minimising environmental impacts. It would also mean lower costs; hence providing the best value for money for consumers.

In another study, we reviewed the use of a canal and river to transfer raw water downstream and reduce the total length of new pipeline. The major benefits of utilising a river/canal for a raw water transfer are reduced extent of construction work, land purchase requirements, engineering assessments and planning permission applications. This would result in lower costs overall and reduce the impact on a number of both urban and rural roads. An additional study involved searching for abandoned pipes and boreholes that could be brought back into service to improve aqueduct resilience. However, no suitable combination of abandoned pipes and boreholes were identified.

New raw water sources

The use of new raw water sources would reduce the reliance on the aqueduct to supply water. One route which is available to increase supply is through borehole extractions. A small proportion of Manchester's current water supply is provided by boreholes; however, there is a possibility to increase this through tapping into new sources. We have examined abstraction points within Greater Manchester, as well as locations further afield. Another major opportunity exists in identifying new river abstractions, which are not currently being utilised. We have identified potential river sources throughout the catchment and studies have been carried out to assess the feasibility of increasing supply.

An innovative option that we have explored is to engage in water sharing with other UK water companies. There has been some discussion between United Utilities and a neighbouring water company, with the possibility of installing a pipe capable of transporting water in either direction. In an emergency situation where one company has a shortage of supply, water can be sent into the network in which it is required.

We have also explored some more unconventional solutions to increase the availability of clean water. Examples include installation of a Reverse Osmosis plant designed to treat wastewater effluent and the use of Graphene for water treatment.

New treatment works

There is a possibility that a number of new water treatment works could be built to improve resilience. In the past five years, there have been two aqueduct outages, where we have isolated flow through the aqueduct in order to assess its condition. To be able to do this, we have had to ensure maximum capacity of our reservoirs; thereby, ensuring a continuous supply during the outage. This however, only gives a short window of time to inspect the condition of the aqueduct. We have undertaken studies to assess the benefit of building new water treatment works which can treat river-source water, at various points along the route of the aqueduct. The advantage of this is two-fold, as it provides an alternative source of water if the aqueduct were to fail, and allows for longer outages to be planned than has been the case previously.

Another option under consideration is increasing the flowrate of an existing abstraction, and re-routing the additional flows to a new treatment works, capable of supplying the Manchester network. Through additional connectivity, overall resilience would improve, as the source of raw water could be selected based on prevailing conditions in the wider network.

New network improvements

Several network modifications were proposed and investigated due to the following scenarios:

- The existing network is not capable of supplying additional flow to the proposed/existing destinations
- No existing water pipeline or network near the alternative water source and/or treatment works

In some options, a new connection would also be required between the existing water take-off point and new treatment works. Addition of new pipelines would improve aqueduct resilience and wider water supply security.

A.4 Additional benefits delivered

M&PR options were developed alongside wider business needs. This is highlighted particularly with aqueduct repair, and other resilience schemes.

A joint working group was set up, between the teams working on supply demand and resilience options, to ensure that the project solutions were mutually compatible, were not competing for the same raw water resources and were not building insufficient or excessive resilience into the system.

This resulted in one potential option being considered where a combined solution could be used for supply demand, M&PR and wider resilience needs. This was a hybrid solution where the initial scopes of solutions were modified. Environmental benefits would be seen from reducing the number of raw sources, new WTW's, the length of new pipework, and overall energy requirements.

There is another associated benefit which may result from the implementation of an upgrade to the West-East Link Main (WELM). It would give added flexibility for supplying West to East, should it be needed for other reasons. This would be particularly the case if, in the future, additional sources of water need to be developed in the western part of the supply system. This might be the case, for example, to meet other resilience drivers. The additional water would then also provide benefit to the eastern part of the supply system.

A.5 Impact on probability, consequences of failure and impacts on service

We engaged with customers on the topic of resilience, the aqueduct risk and the relationship between risk mitigation and cost. In order to effectively communicate this, we determined a range of viable solutions that reduce risk to different levels and calculated the associated bill impact. To determine the viable solutions, we undertook a cost-benefit analysis (CBA). The CBA outputs clearly showed the relationship between solution cost and benefit (at this stage, benefits were equal to the level of risk reduction). This allowed a set of solutions to be identified based on the lowest cost solutions to deliver a range of residual risks (i.e higher cost solutions which gave the similar benefits were discounted at this stage. The solutions that were chosen to represent a choice between residual risk and bill impact for customer research and consultation are summarised below.

A.6 Solutions short list

This section shows the detail of the solutions that have been selected as alternatives for consultation and customer research. Flows for each of these solutions were determined based on historical flows and/or MISER modelling.

<u>Option A: Target repairs of the two tunnel sections that are in the worst condition</u>

This option focuses on addressing the highest remaining risk to water supply. New sources would be required to supply some customers during the rebuild, and these would also provide some alternative water supply for the future. The scope includes:

- Repairs to be undertaken during longer duration outages. Offtake points would require alternative water supplies for the outage period.
- New 5 Ml/d WTW in Rossendale fed from a new abstraction on the River Irwell (similar to water resources option WR141).
- Isolation valves added to the two sections being repaired.
- Uprate West-East Link Main to 150 Ml/d.
- Leakage reduction across various Demand Management Zones (note that this is not additional to the leakage reduction already included in WRMP19 alternative plans 2, 3 and 4).
- Rezoning in Rochdale Demand Management Zone.

The new abstraction would be used intermittently to support outages of the aqueduct to enable repairs.

<u>Option B: Rebuild the tunnel section that is in the worst condition and provided targeted treatment for water quality</u>

This option addresses the highest risk to water supply. It also addresses the highest water quality risk. The scope includes:

- Install additional treatment for metals and ultraviolet disinfection at all 12 bulk supply points along the aqueduct.
- Install additional treatment for metals and increased ultraviolet disinfection capability at the Manchester end of the aqueduct.
- Leakage reduction across various Demand Management Zones (note that this is not additional to the leakage reduction already included in WRMP19 alternative plans 2, 3 and 4).
- New tunnels to replace the two highest risk tunnel sections of the aqueduct.
- Four week outage of the aqueduct to install connections.

Option C: Build 5 new water treatment works

This option will treat impurities that could enter the water supply when it is flowing through the aqueduct. The scope includes:

- Re-designation of the aqueduct as a raw water aqueduct.
- New two-stage 450 Ml/d water treatment works near Bury.
- New 80 Ml/d water treatment works near Kendal.
- New 60 Ml/d water treatment works in the Bowland area.
- New 50 Ml/d water treatment works in Hyndburn.
- New 20 Ml/d water treatment works in Rossendale.
- New connections, mains and pumping stations to supply all areas fed from existing bulk offtakes from the new water treatment works.
- Four outages of the aqueduct to install connections.

Option D: Rebuild all tunnel sections

This option addresses all water supply and water quality risks associated with the tunnels. The scope includes:

- Construct new sections of tunnel parallel to the existing aqueduct.
- Construct new wells adjacent to the existing wells.
- Outage of the aqueduct to allow connections between the old and new wells.

Option E: Rebuild all tunnel sections and provide additional sources of water

This option addresses all water supply and water quality risks associated with the tunnels. This option would enable future tunnel maintenance by providing alternative water supply whilst work is being done. The scope includes:

- Construct new sections of tunnel parallel to the existing aqueduct.
- Construct new wells adjacent to the existing wells.
- Uprate West-East Link Main to 150 Ml/d
- Leakage reduction across various Demand Management Zones (note that this is not additional to the leakage reduction already included in WRMP19 alternative plans 2, 3 and 4).
- New 33.5 Ml/d water treatment works in the Bowland area fed from existing licenced sources in the area
- New 40 Ml/d WTW in Hyndburn fed from a new abstraction on the River Ribble (similar to water resources options WR049a and b[6]).
- New 5 Ml/d WTW in Rossendale fed from a new abstraction on the River Irwell (similar to water resources option WR141).
- New 40.5 Ml/d WTW near Preston fed from existing licensed sources on the Rivers Lune and Wyre.
- Outage of the aqueduct to allow connections to the above new sources.

The full capacity of the new abstractions would be only used infrequently as their purpose is to provide redundancy in the event of failures elsewhere in the system.

[6] Note that for the supply demand balance, options WR049a and b were screened out due to climate change uncertainty (Appendix G of the Technical Report – Options Identification). For M&PR the option would be used in a different mode of operation so the climate change screening does not directly apply. Mitigation of climate change impacts on the solution will likely be possible, for example by changing the utilisation or considering the interaction with storage in the system.

At this stage we have assumed that there is no material impact of options A to E on the supply-demand balance position, noting that these are being defined to address a different resilience driver. Their purpose is to provide redundancy in the event of failures elsewhere in the system, or for planned outages. Once the options to address this risk have been further established we will be able to examine how this interacts with other elements of the preferred plan and whether there are any resulting changes to the final supply-demand balance position. We therefore aim to incorporate this element further into the final plan following consultation if necessary. However, it should be noted that this is not expected to impact on water trading options (Alternative Plan 4 in the main report), which relate to medium-long term needs and are selected to maintain the pre-trading level of resilience for customers.