Final Water Resources Management Plan 2019

Technical Report - Options appraisal

1. Introduction

This technical report sets out our approach to options appraisal to ensure our Water Resources Management Plan 2019 (WRMP19) represents the most cost-effective and sustainable long-term solution, via a “best value” plan. Our approach has been informed by what customers, regulators and other stakeholders have told us, including during our pre-consultation activities. This version of the report also includes appropriate changes following consultation on our draft Water Resources Management Plan, which took place in spring 2018.

This document shows how we have utilised the UKWIR decision making framework[1] and:

- Assessed the requirements for each of our resource zones over the planning period[2];
- Applied existing[3] planning approaches, termed “core methods”, across all resource zones, where appropriate (see Section 2.2); and
- Augmented the core planning approaches, in line with the outcomes of our problem characterisation exercise (see Section 2.2), with what we have termed “extended methods” to ensure we select a best-value plan that protects customers and the environment, in the event that national water trading commences (see Section 3.3).

Our *Final WRMP19 Technical Report - Options identification* documents our process of identifying options for WRMP19, including the development of option scopes[4] and the stages of primary and secondary screening. This ensures that the options appraisal process considers only those options that have passed through the screening process, having been assessed for:

- Benefit, in terms of water available for use (WAFU) or demand reduction;
- Cost, including capital and operational, as well as monetised environmental and social[5];
- Environmental impact, including a Strategic Environmental Assessment (SEA), Habitats Regulations Assessment (HRA), Water Framework Directive (WFD) assessment and Invasive Non Native Species (INNS) assessment; and
- Vulnerability to climate change.

Options appraisal takes these assessments further to understand the in-combination effects of any preferred plan and alternatives, including any effects on greenhouse gas emissions and water quality (see Section 5). Costs in the report have generally been presented as net present values[6] (NPV), or as maximum annual customer bill impacts, whether increases or reductions. At this stage of the water resources planning process costs should be considered as indicative and subject to change.

[1] From WRMP 2019 Methods – Decision Making Process: Guidance (UKWIR, 2016), this is an update to the framework in Water Resources Planning Tools (UKWIR, 2012) that we used for WRMP15 (we selected the “Intermediate Framework”, based on a feasibility assessment), which was an update to The Economics of Balancing Supply and Demand (UKWIR, 2002)

[2] Over a minimum of 25 years, but for some aspects out to the 2080s

[3] Termed “Current (baseline) approaches” in WRMP 2019 Methods – Decision Making Process: Guidance (UKWIR, 2016)

[4] Including the estimated amount of time needed to investigate and implement each option, with an earliest start date based on that review. It’s worth noting that, in this report, we have used a short name for each option, whereas our *Draft WRMP19 Technical Report - Options identification* will refer to the full option name. The “WR” reference is consistent between the two reports.

[5] Environmental and social costing (or “valuation”) has been carried out for us by Amec Foster Wheeler (now known as Wood plc). It helps us understand the value of the impact an option might have on the environment and local community, in terms of: accident risk; carbon; congestion; pedestrian delays; low pressure; supply interruptions; and noise pollution.

[6] Calculated by subtracting the present values (or the “current worth of a future sum of money”) of cash outflows (including initial cost) from the present values of cash inflows over a period of time.

Final WRMP19 Technical Report - Options appraisal

1.1 Changes from draft to final WRMP

Change	Reason	Update(s)	Relevant section(s)
Update of preferred plan for final plan	Update of preferred plan taking account of consultation feedback on draft WRMP, latest customer engagement, water trading position and updated options appraisal.	Updated to reflect selection of Manchester and Pennines resilience solution, further enhanced leakage reductions, removal of water trading from preferred plan, and inclusion of latest aligned options appraisal outputs	Section 5
Addition and restructure of report for adaptive pathway on water trading	Allows presentation of a potential future water trading strategy to reflect removal from preferred plan, as an adaptive pathway from the preferred plan.	Relevant material removed from Section 5, and options appraisal updated to reflect latest underpinning preferred plan position and consultation feedback on options	Section 6
Further explanation of options appraisal process with extended methods	Raised by some stakeholders in consultation. Ofwat specifically also asked about process to identify enabling works for water trading	Addition of summary diagram of overarching options appraisal process Addition of further explanation of water trading enabling works	Section 4 Section 6.4
Provided viable alternative options should national water trading be adopted	Recommendations 1.2 to 1.5 raised by the Environment Agency.	Following the feedback from customers, regulators and stakeholders, through our *Draft WRMP19* consultation, we have proposed a new portfolio of options in the event that national water trading commences.	Section 6
Included a scenario relating to the Windermere Licence Review	Recommendation 3.2 raised by the Environment Agency.	We have incorporated one of the scenarios from the review into our testing of the preferred plan.	Section 7
Reassessed the planned level of leakage reduction and associated programme	Raised by the Environment Agency (Recommendation 4), Ofwat and several other stakeholders.	We have carried out more customer research and have taken on board the views of regulators and stakeholders, through our *Draft WRMP19* consultation, to reassess our planned level of leakage reduction and plan to achieve this.	Section 3.1
Assessed greenhouse gas emissions for current baseline and future operations	Recommendation 5.2 raised by the Environment Agency to ensure compliance with Defra WRMP Direction 3(d).	We have added a chart to show the greenhouse gas emissions for both our current baseline and future operations.	Section 5.2.2
Incorporated the updated baseline supply and demand forecasts	We have updated the ”base year” of our WRMP19 demand forecast to 2016/17 (as stated in draft plan) and we have updated our supply forecast to incorporate, for example, the latest Water Industry National Environment Programme (WINEP).	The main updates are shown in our *Final WRMP19* main report, *Final WRMP19 Technical Report - Demand for water* and *Final WRMP19 Technical Report - Supply forecasting.* However, the resulting supply-demand balance position is also discussed in Section 2.5 of this report.	Section 2.5

2. Approach

This section aims to provide some background and context to items relevant to options appraisal, as well as describing the approach we've taken to determine the most applicable methods in line with the UKWIR decision making framework[7].

2.1 Resource zones

Following our WRMP19 Water Resource Zone Integrity review, as documented in our *Final WRMP19 Technical Report - Supply forecasting*, we have four resource zones:

- The Strategic Resource Zone (SRZ), a combination of the Integrated Resource Zone and West Cumbria Resource Zone by 2021, covering over 98% of customers;
- The Barepot Resource Zone (BRZ), a newly created resource zone containing industrial customers on non-potable supplies;
- The Carlisle Resource Zone (CRZ); and
- The North Eden Resource Zone (NERZ).

2.2 Core methods

In previous WRMPs, we used two core methods to inform decisions:

- Average Incremental Cost (AIC) and/or Average Incremental Social Cost (AISC) ranking; and
- Economics of Balancing Supply and Demand (EBSD) modelling or, sometimes, "EBSD optimisation".

The results of these have previously been combined with quantitative customer research, as well as more qualitative environmental and resilience type assessments, to aid decision making. We referred to this method as a type of "manual multi-criteria analysis". A description of AIC and AISC is given in Table 1. Both AIC and AISC involve the calculation of the whole-life cost of each option over 80 years in pence per cubic metre (p/m^3). Whole-life costs[8] include treatment, pumping, network, storage, maintenance and operating costs. The AISC values for all our feasible options are shown in Appendix A.

Table 1 The definition AIC and AISC and how it is calculated for each option

Term	Acronym	Meaning	Calculation
Average Incremental Cost	AIC	A metric to present the unit cost of the extra water available for use or demand saving from a particular option	The net present value[9] of the capital (including maintenance and replacement costs, as well as the cost to finance the capital) and operating costs of the option, divided by the net present value of the extra water available for use or demand saving.
Average Incremental Social Cost	AISC	A metric to present the unit cost, accounting for environment (including carbon impacts) and social cost, of the extra water available for use or demand saving from a particular option	The net present value[9] of the capital (including maintenance and replacement costs, as well as the cost to finance the capital), operating, environment and social costs of the option, divided by the net present value of the extra water available for use or demand saving.

AIC and/or AISC ranking is one of the simplest, aggregated options appraisal techniques and, with expert judgement, allows the creation of a low cost, although not an optimised "lowest cost", investment programme[10] (or "schedule"). EBSD modelling was formulated in a key methodology document[11] published by UKWIR in 2002 to do this.

[7] From WRMP 2019 Methods – Decision Making Process: Guidance (UKWIR, 2016), this is an update to the framework in Water Resources Planning Tools (UKWIR, 2012) that we used for WRMP15 (we selected the "Intermediate Framework", based on a feasibility assessment), which was an update to The Economics of Balancing Supply and Demand (UKWIR, 2002)
[8] All prices are base dated at 2017/18, using the retail price index (RPI)
[9] Calculated by subtracting the present values (or the "current worth of a future sum of money") of cash outflows (including initial cost) from the present values of cash inflows over a period of time.
[10] There is a choice around including option utilisation, calculated by building the options into our Aquator™ water resources models and running the system at an average demand level, in AISC values when ranking options. We have presented AISC values at capacity, rather than at utilised capacity, in Appendix A, but have utilised both approaches when considering option ranking.
[11] The Economics of Balancing Supply and Demand (UKWIR, 2002)

EBSD modelling uses a similar whole-life costing approach to AIC and AISC, but can be used to solve any supply-demand deficits in the planning period by optimising[12] option start years. Once run, the optimiser displays the results of the optimum (lowest total NPV option set, while meeting the total deficit constraint) set of selected options, with the start year for each option. An optimisation summary, log of all simulations and log of progress steps are then reported. This process avoids indivisibilities[13] in the final solutions that can occur if the AISC approach is used to determine the optimal solutions (when creating a schedule).

However, EBSD modelling is still a relatively simplistic aggregated options appraisal technique and there are limitations when dealing with complex conjunctive use resource zones. The combined supply benefit of a group of resource management options is likely to differ from the sum of the individual options as they are typically to some extent mutually beneficial or exclusive (for example, two options might be situated upstream of the same critical network constraint). This is one of several reasons that we employed the use of extended methods.

2.2.1 Cost profile and discount rate for whole-life costs

The cost profile is the length of time option costs are considered over; it is longer than the planning period during which time options can be implemented. At WRMP15, we used a 25 year planning period and a 105 year cost profile. The Environment Agency questioned this approach, as we had not aligned to the 80 year cost profile in the 2013 Water Resources Planning Guideline[14]. Our reasoning was that, in EBSD modelling, an option can be chosen in any year of the 25 year planning period from 1 to 25. Therefore, options selected in year 25 need a further 80 years of cost profile to achieve a cost profile of a minimum of 80 years, hence 105 years. We engaged with the Environment Agency in 2016 and discussed the different potential cost profiles for WRMP19. Following this, we have adjusted the way we calculate option costs:

- Our AISC values are now calculated using an 80 year cost profile; and
- Our EBSD modelling allows an option start year to be at any point in the planning horizon (years 1 to 25) and, from that point, applies a minimum cost profile of 80 years.

In line with the 2017 Water Resources Planning Guideline[15], the net present value of all costs has been calculated using the Treasury Test Discount rate, as set out in the HM Treasury "Green Book"[16]. This is 3.5% for years 0 to 30 of the appraisal period, 3.0% for years 31 to 75, and 2.5% for years 76 to 125.

2.3 Problem characterisation and initial method review

An important step in the framework resulting from the UKWIR Decision Making Process project[1], "problem characterisation" allows us to evaluate "strategic needs" and complexity, to understand the level of concern required for each of our resource zones and tailor our approach.

In March 2016, we shared our initial problem characterisation[17] with the Environment Agency for feedback. We subsequently discussed this further with Ofwat and Natural Resources Wales, prior to our wider pre-consultation activities. This ultimately culminated in a methodology statement of our problem characterisation and approach selection, which was shared with the Environment Agency, Natural Resources Wales and Ofwat at pre-consultation in autumn 2016. A briefing note was also provided to stakeholders as part of pre-consultation to explain our intended approach to building the plan, supported by public events.

The rest of this section, and Section 2.4, explains briefing how our problem characterisation and approach selection was developed. A summary of our initial problem characterisation is shown in Figure 1.

[12] For WRMP15 and WRMP19, we used software created by Palisade called Evolver. This uses innovative "mutations" and combinations of solutions, or "organisms," and is well-suited to finding the best overall answer.
[13] An option is indivisible if it has a capacity below which it is unavailable, at least without significant qualitative change in scale and scope.
[14] Water Resources Planning Guideline (Environment Agency, 2013)
[15] Water Resources Planning Guideline (Environment Agency, 2017)
[16] The Green Book: Appraisal and Evaluation in Central Government (HM Treasury, 2003)
[17] The Barepot Resource Zone was not a resource zone at this stage, having only been created through the WRMP19 process. However, we have presented it in Figure 1 for completeness.

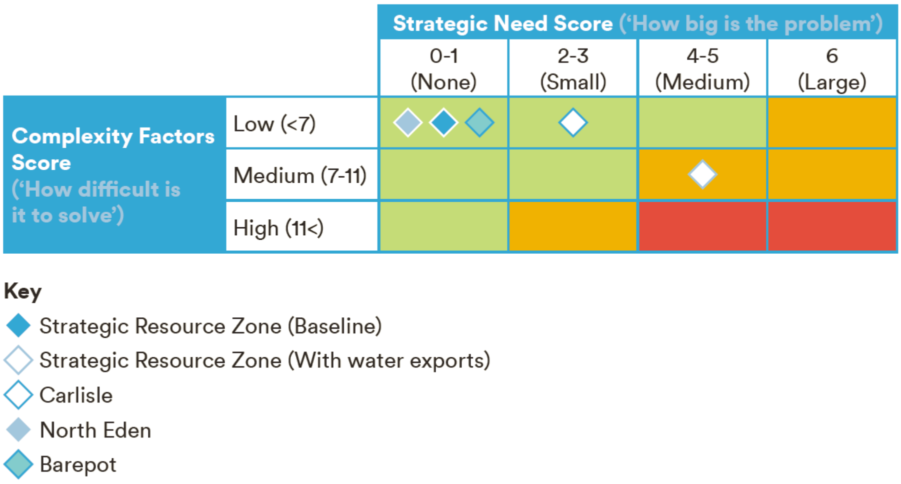

Figure 1 Summary of initial problem characterisation scores

Following the initial problem characterisation and following review by Atkins, the key outcomes were that:

- The baseline[18] view for all resource zones was of "low level concern", based on a low complexity factors score and a relatively low strategic needs score; and
- A "moderate" level of concern and added focus was required for the Strategic Resource Zone, due to a strategic need, now termed a "strategic choice", around national water trading. This was a key driver for the application of, the more sophisticated, extended methods in the Strategic Resource Zone, discussed further in Section 3.3.

Table 2 shows the chosen decision making approach/method type, based on our problem characterisation.

Table 2 Decision making approach/method by resource zone, with rationale

Resource Zone	Decision making approach/method type	Rationale
Strategic	Extended	Resource zone was of "moderate level concern", due to strategic choices
Barepot	Core	Resource zone was of "low level concern"
Carlisle	Core	Resource zone was of "low level concern"
North Eden	Core	Resource zone was of "low level concern"

Our problem characterisation triggered an initial method review to consider the different types of extended decision-making methods available[19]. We considered how best to add value to the core methods, taking into account proportionality in terms of the "strategic choices" and system complexity. When assessing the different decision-making methods, the UKWIR methodology[19] specifies four key elements for consideration, as shown in Figure 2.

[18] This is what would happen if we did not take any new supply or demand actions and did not implement any changes in our company policy or existing operations

[19] WRMP 2019 Methods – Decision Making Process: Guidance (UKWIR, 2016)

Figure 2 Four elements of decision making methods to be considered when selecting the appropriate method[20]

Each of these is taken in turn in Table 3 to assist with articulating our choice of approach, showing which methods were screened out as we progressed through each element. To reiterate, extended methods were explored to complement the core methods and aid development of the most cost effective, best value plan. Reference is made to the core methods where relevant and Figure 3 shows the different decision-making methods available.

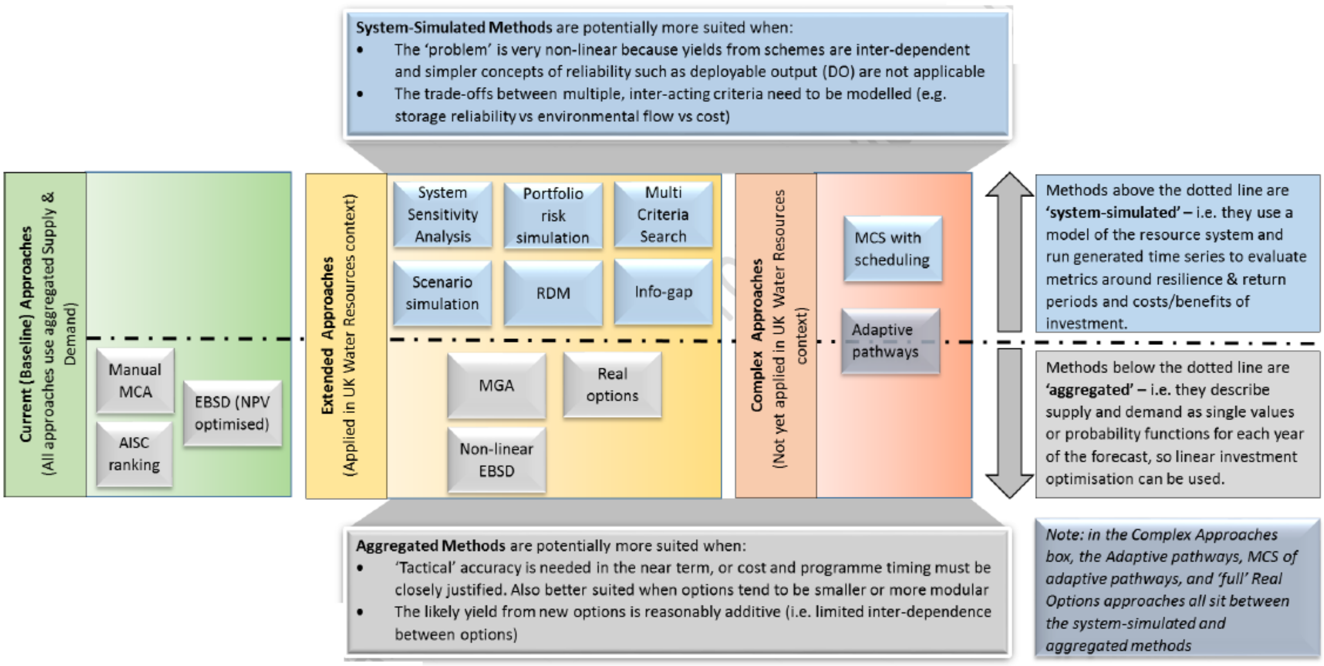

Figure 3 Decision-making methods, with a description of system-simulated and aggregated methods[20]

[20] From WRMP 2019 Methods – Decision Making Process: Guidance (UKWIR, 2016)

Table 3 Our consideration of the four elements of decision making methods from the methodological briefing of our initial problem characterisation and approach selection

Element	Consideration	Method(s) screened out
Objectives	Our Strategic Resource Zone is complex and non-linear and aspects such as deployable output may not fully capture all aspects of system performance, e.g. risk and resilience. Similarly, the scale of a supply-demand balance may not fully reflect the level of risk and resilience across the resource zone to different types or severities of future drought events, particularly under water trading scenarios. By examining multiple criteria, we can better appraise a wider range of considerations in future water resources management, and use these to help define a best value plan in a structured manner.	Single metric methods
Approach	At WRMP15, we utilised AISC ranking to complete a coarse screening of options, followed by EBSD optimisation to define the lowest cost and alternative plans. A "manual multi-criteria analysis" approach was then used to select between these plans. This is an 'aggregated' approach, dependent on the concept of the "supply-demand balance" over a pre-specified planning period. Aggregated methods describe supply capacity and demand as single values (e.g. as deployable output as the supply and "dry year" demand for a reference demand position). The orange zone in Figure 3 shows the range of methods that may be applied under an 'extended approach'. We did not consider 'complex approaches' given the timescales involved for WRMP19 and the scale of vulnerability based on the outcomes of the 'problem characterisation' (multi-criteria search with scheduling and adaptive pathways have therefore effectively been 'screened out' at this stage). As shown in the grey box on the lower portion of Figure 3, aggregated approaches treat yield or deployable output as additive, and are best for 'tactical' decisions to define year on year programme accuracy (also portrayed in the next section) in the near term. For the Strategic Resource Zone, as described in the problem characterisation, individual option deployable output is not additive, given the interdependent nature and complexity of the system (in part, this is why for conjunctive use systems companies use water resources models like Aquator™ rather than simply add up individual source deployable output to estimate water available for use), but rather is highly non-linear. For a unit Ml of water added to the system, the benefit will depend on the type of source and its location in the supply system. Similarly, in considering water trading, the point in time that we may need to export water (and build options to implement this) will largely be determined by the receiving company WRMP as to when the water is required, so the decision-making method does not need to focus on timing of investment. The large uncertainties and key questions are long-term, not near-term. We have recognised the limitations of aggregated approaches to WRMPs, and in part used this to improve its appraisal of options appraisal outputs (e.g. iterative testing of EBSD option sets in Aquator™ models), however, significant additional understanding may be gained from a 'system-simulated' method. The blue box at the top of Figure 3 describes where simulated methods may be of greater value. As can be seen, this describes application on non-linear systems and where multiple-criteria need to be appraised (as in a complex appraisal to examine water trading against a background of planning uncertainty). For this reason, we explored extended methods in the upper half of the diagram, and others in the lower portion of the diagram have been discounted.	Multi-criteria search with scheduling Adaptive pathways

Element	Consideration	Method(s) screened out
Solution	Closely related to the consideration of approach, the plan solution should be considered. Of the three types listed in the UKWIR report[21], there is only one 'adaptive strategy' approach in the UKWIR methodology, that of 'adaptive pathways', so as an advanced approach that is unproven or tested in WRMPs this has not been considered. We have however developed a plan consistent with adaptive planning principles. This leaves two types of solution, portfolios or schedules. The existing WRMP supply-demand balance and EBSD approach is a good example of a schedule, as the outputs define both the options for the plan, and when on the horizon these should be developed over time. This is represented by different plan interventions, defined and appraised over time. This is 'tactical' accuracy. However, as described in the previous section, our choices for the Strategic Resource Zone relate to water trading in the context of future uncertainty, to ensure this represents 'best value' and is resilient to change in the long-term (as opposed to the minimum, least-cost solution defined using an EBSD approach). Therefore, it is more appropriate to pick key points in time (e.g. at 10 year, 25 year and potentially longer into the planning horizon), and test how a range of options (portfolios) perform at that discrete point in time to a wide range of uncertainties. Against, these long-term uncertainties, the year on year 'accuracy' of a schedule is of less interest. We, therefore, examined a 'portfolio' approach, given the long-term strategic nature of its considerations. Such an approach also enables better consideration of changes in levels of service against the background of longer-term uncertainty (e.g. climate change). Generally speaking, portfolio approaches are usually mapped to system-simulated approaches, as can be seen by the number of portfolio methods in the list. Portfolio Risk Simulation (PRS) has, therefore, been screened from the potential methods under consideration at this stage (it also requires a very high number of model runs, limiting the number of schedules that may be tested in the analysis).	Aggregated methods, other than those used as core methods Portfolio Risk Simulation (PRS)
Selection	Broadly speaking, there are two types of selection approach to defining the resulting solutions for consideration in the WRMP. 'Expert judgement' type approaches use the wealth of information from the options appraisal (i.e. performance metrics for different options sets) to select appropriate solutions. Those remaining use analytical approaches (e.g. optimisation or ranking) to identify potentially 'optimal' solutions. It should be noted that, as with the core methods, both of these realistically utilise 'expert judgement' or decision-making to define the solutions and WRMP. The decision-making methods are there to assist in decision-making, not to make the decisions, nor can all aspects of the planning process be fully quantified (e.g. qualitative stakeholder feedback from consultation, SEA outputs etc.). With reference to the UKWIR report[21], we screened out one more method at this stage of the process, System sensitivity analysis. This method has been developed almost entirely with climate change risks in mind. Although this represents one of our key uncertainties in the long-term, it is not the only consideration in the context of the Strategic Resource Zone and the strategic challenges faced, so has been discounted on this basis (rather than based on 'approach' criteria). We also considered screening out multi-criteria search on the grounds of complexity. This method requires Genetic Algorithm optimisation of portfolios and a high degree of modelling automation. The approach is stated as likely for use on plans with very significant concerns from 'problem characterisation', particularly where a company might face criticism from stakeholders over the range of portfolios that it chooses to analyse (for example, "very significant strategic investment needs"). Given that we are already relatively advanced in exploring Genetic Algorithm optimisers for control curve analysis, this may be a consideration in future planning rounds (WRMP24 and beyond) to build on the system-simulation approaches in WRMP19.	System sensitivity analysis

Following our consideration of the four elements of decision making methods in Table 3 and the screening out of several methods, as shown, there were four potential extended methods remaining:

- Scenario Simulation
- Robust Decision Making
- Info-gap Analysis
- Multi-criteria search

The next section describes our selection of the final approach from these four methods.

2.4 Detailed method review and method selection

As described in the previous selection, a screening approach was used to select four potential methods for implementation in support of EBSD at WRMP19. These choices were consistent with our view that a system-

[21] WRMP 2019 Methods – Decision Making Process: Guidance (UKWIR, 2016)

simulation, portfolio approach was most likely to add value to WRMP19 to supplement the core decision making methods. The potential choices, along with our findings and initial screening outcomes are shown in Table 4 below. As part of this process we also selected a risk composition for each resource zone in line with the UKWIR risk based planning framework[22]; this is outlined in our *Final WRMP19 Technical Report - Supply forecasting.*

Table 4 Summary of more detailed method screening process carried out in 2016

Method[23]	Method screening findings	Method screening outcome
Scenario Simulation	Strong links to core approach and comes with the advantage of using established Aquator™ water resources models.	Continue to investigate
Robust Decision Making	Allows a much greater range of uncertainty to be explored. However, necessitates the use of a faster, simplified model, with associated trade-offs.	Continue to investigate
Info-gap Analysis	Similar approach to Robust Decision Making, but uncertainties perturbed from a central estimate. Simplified model requirements are identical.	Continue to investigate
Multi-criteria search	Lots of potential benefits. However, with the large range of future uncertainties to be explored, multi-criteria search was considered to be too intensive to facilitate this.	Cease investigation

We undertook a further, more detailed, review of the remaining three methods to establish the most suitable approach. Whilst Scenario Simulation and Robust Decision Making were both found to be applicable, the benefits of Info-gap Analysis were outweighed by the practicalities of implementation. The main issue in adopting an Info-gap Analysis approach was that many of the issues that needed to be explored were not readily quantified on the continuous basis that underpins Info-gap Analysis type approaches[24]. Therefore, the chosen extended methods approach was a combination of Scenario Simulation and Robust Decision Making, termed:

Scenario Simulation, with Robust Decision Making principles

This selection allowed us to utilise our existing Aquator™ water resources models and capabilities for an accurate simulation of the system, but also supplement this with a Robust Decision Making type assessment in a faster, simplified model built in Pywr[25] water resources software to explore a wide range of uncertainties. This process is described in Section 4.

2.5 Our baseline supply-demand position

The baseline supply-demand balance for each of our resource zones is shown in Section 4.6 of our *Final WRMP19* main report. The overarching message from our *Draft WRMP19* was that all four of our resource zones were in surplus to 2044/45, negating the requirement for EBSD modelling to solve any baseline supply-demand deficits.

However, with the demand increases over the last few years combined with small further reductions in supply available driven by Water Industry National Environment Programme (WINEP) changes, we are now forecasting a very small baseline deficit in our Strategic Resource Zone between 2040/41 to 2044/45. While this baseline deficit required EBSD modelling to solve, the most cost effective solution was leakage reduction and this already formed one of several strategic choices at the draft plan stage, which we have consulted upon. The strategic choices result in a long-term final planning surplus without requiring further intervention or appraisal of options. These strategic choices are summarised in Section 3 below.

2.6 Customer support for each option type

This section describes two sets of customer research that gives us an understanding of the support for each option type. These are discussed in detail our *Final WRMP19 Technical Report - Customer and stakeholder engagement*, and only summarised here. The first, completed in June 2017 used more traditional survey techniques (WRMP19

[22] WRMP 2019 Methods – Risk Based Planning (UKWIR, 2016)
[23] A full description of each method can be found in WRMP 2019 Methods – Decision Making Process: Guidance (UKWIR, 2016)
[24] Primarily geared towards identifying when choices of options 'switch' as future conditions are varied from the central estimate
[25] Pywr is a generalised network resource allocation model written in Python. It can be used for solving network resource allocation problems at discrete time steps using a linear programming approach, with a principal application in resource allocation in water supply networks. It was developed by Atkins and the University of Manchester.

customer preferences: Phase 2 quantitative research – June 2017), whilst the second used new innovative techniques to engage with customers to ensure our investments and activities reflect customer priorities in an innovative interactive tool (Programme Choice Experiment – September 2017 and April/May 2018).

Table 5 and Figure 4 show the customer support for each option type from the more traditional techniques, weighted against the base case of more frequent temporary use bans[26]. It's worth noting that cost was not shown in this research given that aspect is covered as part of the options appraisal process itself and, for example, all desalination options were screened out in secondary screening, based on cost.

Table 5 Customer support for each option type, weighted against the base case of more frequent temporary use bans (i.e. more frequent temporary use bans is 1, with higher preference options having a higher ratio than 1) and not considering the cost of each type of option

Option type	Household customers	Non-household customers	Comments
More frequent temporary use bans	1	1	Base case
River abstraction	1	3	
Desalination	4	5	
New reservoir	3	2	
Increase existing reservoirs	3	2	
Transfer from outside our region	1	1	
Transfer within our region	2	1	
Metering	3	3	
Water efficiency	5	3	
Recycle water (directly)	2	2	
Recycle water (indirectly)	1	2	
Leakage reduction	10	6	Most favoured option type
Groundwater	1	1	
More frequent drought permits	0.4	0.6	Least favoured option type

[26] Via "odds ratios"

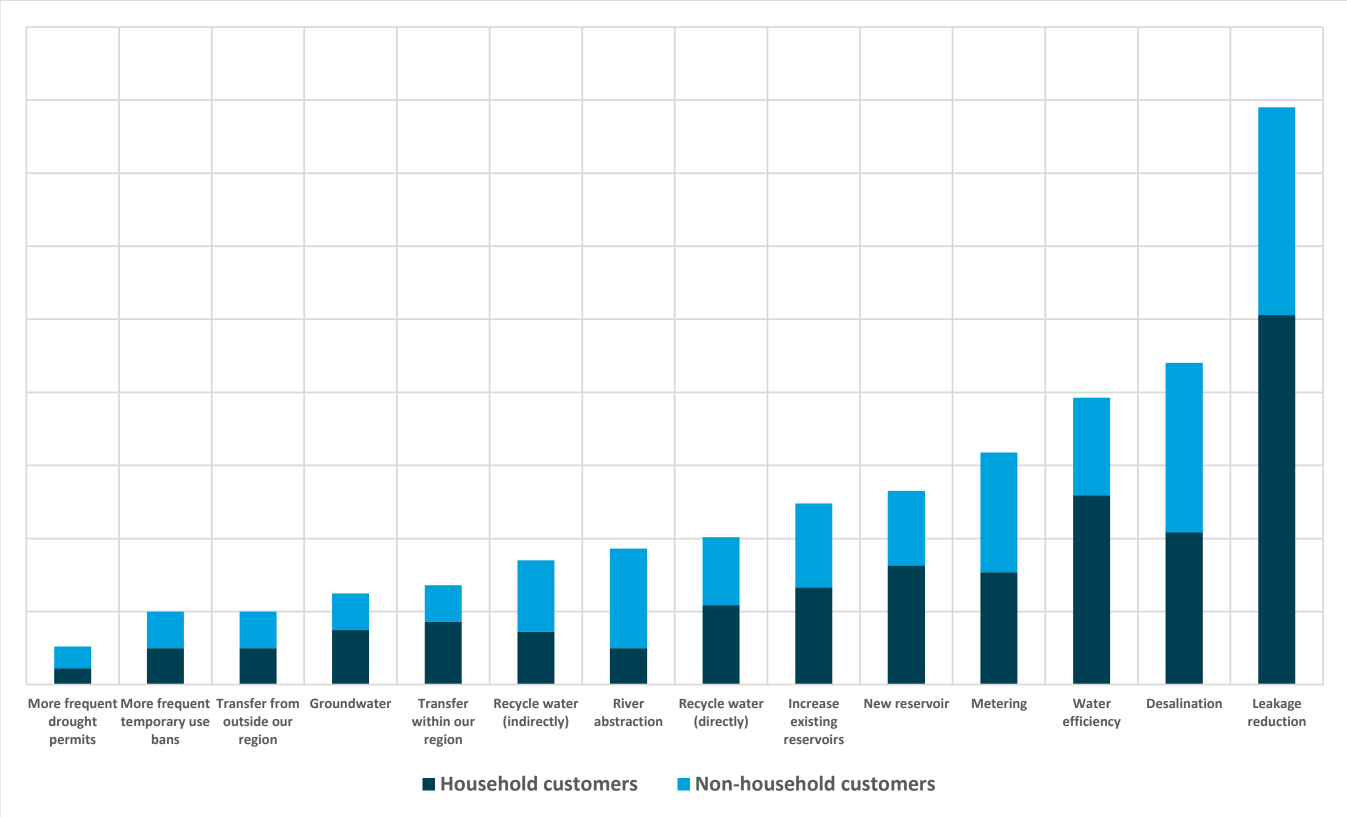

Figure 4 Customer support for each option type, weighted against the base case of more frequent temporary use bans and not considering the cost of each type of option

A clear preference can be seen for leakage reduction and water efficiency type options and we have used this, along with several other factors, in the appraisal of the different options. Although this research was principally to determine support for options to address a supply-demand deficit, it was also used to inform wider choices. Leakage reduction became a strategic choice for the plan given the very high level of preference, as discussed in Section 3.1, whilst metering and water efficiency type interventions were also incorporated into our baseline forecast. This is in part to retain our ambitious baseline per capita consumption reduction levels, as set out in our *Final WRMP19 Technical Report - Demand for water*.

Table 6 shows some key themes and outcomes from the second exercise, particularly useful in the context of some of our strategic choices, discussed in the next section.

Table 6 Key themes and outcomes from our customer research (Programme Choice Experiment – September 2017)

Theme	Outcome
Leakage	• Willingness to pay for leakage reduction of 44 Ml/d, on average (based on preference over supply schemes); and • No preference for reducing visible leakage over non-visible.
Level of service: Temporary use bans (Hosepipe bans) & Drought Permits	• Only 14% of customers wanted less frequent temporary use (hosepipe) bans; • Average choice 1 in 13 years on average for temporary use bans; and • Slight preference for less frequent drought permits (1 in 24 years on average).
Water efficiency	• Most customers chose some water efficiency measures; and • No expensive schemes included so not possible to say whether it would be chosen over schemes to increase supply capacity.
Metering	• 75% metering chosen on average; and • 14% of customers chose no increase.
Resource management options	• Customers chose more water from reservoirs and boreholes, and less from rivers, despite higher costs.

In summer 2018, we repeated our innovative interactive tool (Programme Choice Experiment – April/May 2018) to further engage with customers to ensure our investments and activities reflect customer priorities. This time using the latest option costings and, in the context of leakage reduction, although the outright customer valuation for leakage reduction stayed pretty static, customers would essentially support higher leakage reduction for same cost (or bill impact).

Table 7 Key themes and outcomes from our customer research (Programme Choice Experiment – May to June 2018)

Theme	Outcome
Leakage	• Willingness to pay for leakage reduction of 51 Ml/d, on average, compared with 44 Ml/d previously (based on preference over supply schemes); and • No preference for reducing visible leakage over non-visible.
Level of service: Temporary use bans (Hosepipe bans) & Drought Permits	• Only 16% of customers wanted less frequent temporary use (hosepipe) bans (14% previously); • Average choice 1 in 13 years on average for temporary use bans, the same as previously; and • Slight preference for less frequent drought permits (1 in 24 years on average), the same as previously.
Water efficiency	• Most customers (88%) chose some water efficiency measures; and • No expensive schemes included so not possible to say whether it would be chosen over schemes to increase supply capacity.
Metering	• 81% metering chosen on average (75% previously); and • 13% of customers chose no increase (14% previously).
Resource management options	• Customers chose more water from reservoirs and boreholes, and less from rivers, despite higher costs.

This research, along with regulator and stakeholder feedback as part of our consultation on the draft WRMP19 submission, has driven a large change to our leakage reduction strategy, discussed further in Section 3.1.

3. Strategic choices for our region

When considering any strategic choice, we have several important overarching aims and these are:

- Selecting and defining choices on the basis of customer and stakeholder views;
- Ensuring we protect our customers, whether this be with regards to affordability, resilience or the quality of water being provided;
- Ensuring we protect and, where possible, enhance the environment, including meeting the objectives of environmental legislation[27] such as the Habitats Directive and Water Framework Directive; and
- Ensuring our plan can adapt to factors that are not entirely within our control or that may fundamentally change future plans, i.e. water trading requires agreement from both parties, via plan "adaptive pathways".

The strategic choices, as outlined in our *Final WRMP19* main report, are shown in Table 8. Our *Final WRMP19 Technical Report - Customer and stakeholder engagement* documents the wide array of customer and stakeholder engagement and we have used this, as well as the option preferences in Section 2.6, to guide our decision making.

Table 8 Strategic choices for WRMP19

Strategic choice summary	Why has this become a strategic choice?	What is the choice?
Enhanced leakage reduction	Customers and stakeholders see this is as a clear priority area. Regulators and government have set out aspirations to reduce leakage further.	How far we go in terms of leakage reduction, balancing with customer affordability, and at what pace?
Improve the stated level of service for drought permits and drought orders to augment supply	Feedback from regulators and other stakeholders, as well as being a commitment in our WRMP15.	Whether to further improve the stated minimum level of service?
Increase the resilience of our supply system to non-drought hazards, such as asset failure	Through a full system-wide review of our resilience to different non-drought hazards, we have highlighted key risks that need to be reduced through investment in our assets.	Should we invest to increase the resilience of our supply system to non-drought hazards, such as asset failure? What type of solutions should we develop?
Continue to explore national water trading from our Strategic Resource Zone	National need[28] and potential to reduce bills for customers, while protecting resilience and the environment.	Do we continue to explore national water trading from our Strategic Resource Zone?

This section aims to provide further detail and evidence for each of the strategic choices, with the main narrative being provided in Section 6 of our *Final WRMP19* main report.

3.1 Enhanced leakage reduction

3.1.1 Justification for the proposed level of reduction

In our *draft WRMP19*, we proposed a reduction in leakage of 7% from baseline by 2024/25 and a total of 30% by 2044/45. There have been a number of changes since the *draft WRMP19* that have been taken into consideration when selecting the options and level of leakage reduction. For our *final WRMP19*, we are reducing leakage by 20% from baseline by 2024/25 based on annual reported total leakage, and just over 40% in total by 2044/45. The table below summarises our final plan leakage target and percentage change from baseline.

Table 9 Comparison of regional target leakage values for final plan between annual and 3-year average leakage reporting

Year	2024-25	2029-30	2034-35	2039-40	2044-45
Baseline position (Ml/d)	**448**				
Leakage target - annual (Ml/d)	357	336	315	287	259
Change from baseline - annual (%)	20%	25%	30%	36%	42%

[27] This is also a key requirement in defining our baseline position, explained further in Section 7 of our *Final WRMP19 Technical Report - Supply forecasting*

[28] In line with the outcomes of the Water resources long-term planning framework 2015-2065 (Water UK, September 2016)

3.1.1.1 Short run Sustainable Economic Level of Leakage (SELL)

The short run Sustainable Economic Level of Leakage (SELL) of 463.2 Ml/d is based on the lowest total cost, of active leakage control and the marginal cost of water. The baseline position of 448.2 Ml/d is already below the SELL, and this means that any further reductions will have an associated cost, which needs to be taken into account as we define the strategic choice. This cost has the potential to impact customer bills and our ability to address customers' other priorities; we need to ensure that all changes we make are overall affordable to customers and have factored in their preference and valuation of demand side options relative to new supply options. We therefore need to ensure that further reductions are assessed in terms of the costs that have the potential to impact customer bills and our ability to address other customers' priorities, but also recognise that there is an avoided cost if reducing leakage defers or removes the requirement for supply side options in future.

Demand management is a significant component of our approach to safeguarding the future of our water supply and the environment. It is a key government priority as, for example, set out in Defra's guiding principles. It has an important role to play in managing the supply-demand balance across the planning horizon, and can benefit resilience to future uncertainty and change. Of areas in which we can manage demand, there are particularly strong feelings around leakage; it is consistently raised as a key concern when we consult with customers and stakeholders. Our regulators have set out a clear challenge to further reduce leakage, and in its recent draft methodology for PR19 Business Plans, Ofwat challenged companies to make a further 15% reduction during the period 2020-2025. Our revised draft plan was based on achieving a 15% reduction in leakage by 2024/25. However, in Ofwat's initial assessment of our proposed business plan for 2020-2025, Ofwat challenged us to bring forward some of our planned leakage reduction activities to achieve an even higher reduction during the period 2020-25. Our final plan therefore includes a proposal to reduce leakage by 91Ml/d (20%) by 2024/25.

3.1.1.2 Consultation and customer support

We received formal comments from thirteen stakeholders through the consultation on our draft WRMP. Twelve of these wanted us to be more ambitious in reducing leakage further, and both Ofwat and the Environment Agency both commented that we needed to be more ambitious.

We have conducted a wide range of specific customer research on leakage, as outlined in our *Final WRMP19 Technical Report - Customer and stakeholder engagement*. This has shown that, as always, there is very strong support for leakage reduction, although it also shows that there are limits due to affordability. Section 4.4 of the aforementioned technical report includes a derived customer valuation. Following further exploration of leakage innovations and options for the final plan, the level of acceptability of £1.74 is between the average annual bill impact of £1.56, and the maximum annual bill impact of £1.96 that we estimate to reduce leakage by 20% in line with the Ofwat aspiration[29]. Therefore, this research shows broad support for us to go further than our proposals in the draft Water Resources Management Plan. This is shown in Table 10 below. Adopting the 20% reduction still seeks to balance the pace of reduction against customer priorities and affordability, as well as practical considerations and recognition of our supply-demand balance position.

Table 10 Bill impact of potential AMP7 (2020-2025) leakage reductions compared to customer valuation

AMP7 leakage reduction from WRMP19 baseline (three-year average)	Where total leakage would be at the end of AMP7 (2025) (Ml/d)	Average annual increase in bill to achieve (pence)	Maximum annual increase in bill to achieve (pence)	Customer valuation expressed as bill impact (pence)
0 Ml/d	448	-	-	-
91 Ml/d (20% below baseline)	357	156p	196p	

[29] Following further exploration of leakage innovations and options costs for the revised draft Water Resources Management Plan, and stretching ourselves further to achieve increased leakage savings for the same cost through increased efficiency.

Consideration of different drivers (on balance), to making a significant reduction in leakage are summarised in Table 11 below.

Table 11 Summary of key drivers for making a significant reduction in leakage

PESTLE category	Key drivers and considerations
Political	• We are an industry outlier using leakage per km and per property metrics at regional level • Reducing demand, including leakage, is a strategic government priority and stakeholder responses have asked us to do more than we set out in our draft plan
Environmental	• Reducing leakage further below baseline is beneficial for the environment • Reducing leakage helps to mitigate the risk of longer-term uncertainty such as climate change and impact positively in relation to levels of service and resilience
Social	• Customers and stakeholders strongly support reducing leakage and wanted us to be more ambitious than our draft plan • The general public and media perceive current leakage levels as being too high, resulting in reputational issues for the industry and resistance against customer water use restrictions during drought • Having a high level of leakage is unlikely to help in persuading customers to reduce their own consumption
Technological	• There are a range of new tools and technologies that are becoming available • Technology and innovation is expected to drive efficiency and change the economics of leakage management
Legislative	• There is no specific legislative driver, however, Ofwat has challenged the industry to set more challenging and stretching leakage reduction targets, or justify why this is not appropriate for a particular company
Economic	• Customers supported on average a 12% reduction in leakage from the Programme Choice experiment that considered wider affordability and bill impact • Customer valuations from acceptability testing supports the 15% reduction • Customer acceptance of bill impact associated with the planned reduction of 15% is supportive

We have proposed to reduce leakage across all resource zones over the planning horizon, however, in the AMP7 planning period (2020-2025) this is focused on our Strategic Resource Zone. As explained in more detail within *Final WRMP19 Technical Report - Demand for water*, the Cumbrian Resource Zones are already operating at a frontier level of leakage, and whilst we expect some of the technological and innovative solutions to provide some benefit in the smaller zones, the benefits are significantly fewer, therefore our short-term reduction is focused in the Strategic Resource Zone. We will still continue to explore the potential for further reductions in these zones in future.

Figure 5 shows our proposed WRMP19 leakage reduction programme, incorporating a 20% leakage reduction in AMP7 (2020-2025). The longer-term leakage reduction aspirations are explained in the next section.

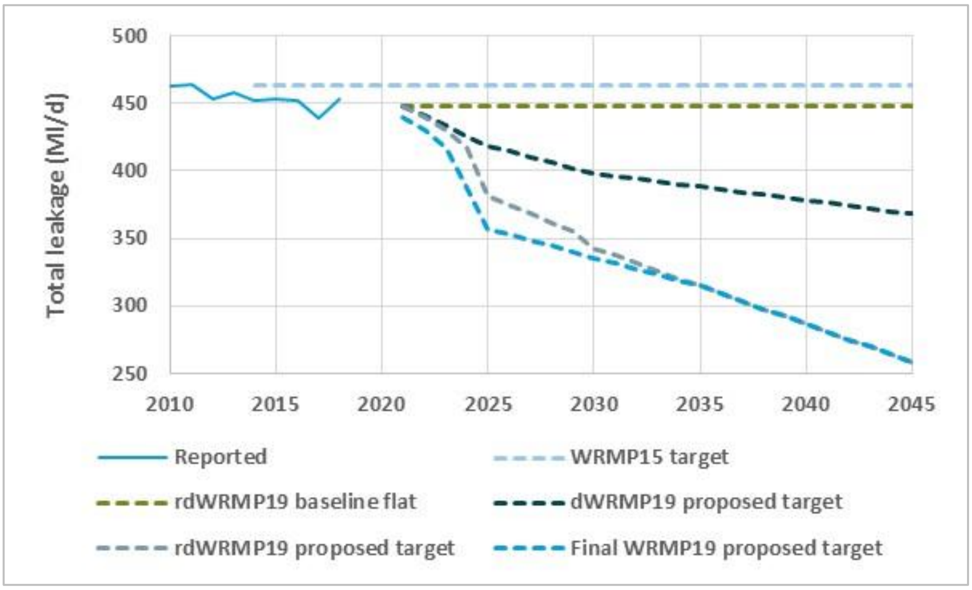

Figure 5 Reported total leakage and our Final WRMP19 proposed target (incorporating a 20% leakage reduction in AMP7), against our WRMP15 target (sometimes referred to as our "current commitment"), a flat target from the Final WRMP19 baseline[30] and our Draft and Revised Draft WRMP19 proposed targets

3.1.1.3 Longer term reductions and uncertainties

We have proposed a total reduction of 190 Ml/d by 2044/45, this level of further leakage reduction reflects just over a 40% change from our baseline commitment. The longer term average annual bill impact based on current options, is a maximum annual increase of £3.25. This long-term aspiration is based on the assumption that future further innovations to reduce leakage will be implementable, and thus reduce the cost of leakage reduction from current levels, ensuring that a broadly comparable pace of leakage reduction can be maintained, whilst recognising the potential for diminishing returns. It is therefore subject to review in future planning cycles using the latest evidence.

It's worth noting that the costs to reduce leakage are likely to change in the future, due to factors like innovation in leakage detection and repair, which has been factored into our long-term aspirations. Therefore, for this WRMP, we have sought to set out a programme that is innovative, cost effective and affordable in the long-term, but balance this with reliability in the shorter term.

Leakage reduction can be implemented incrementally and in stages, with considerable flexibility and does not require the same level of initial commitment that a supply option may require. The pace of reduction can be increased or reduced accordingly over time, and based on the needs of future plans (e.g. if an alternative supply-demand scenario is followed akin to those presented in Section 7). Committing to a reduction of 20% by 2024/25 does not expose customers to undue risk, as leakage reduction options are all scalable in comparison to a new supply option. This provides a degree of flexibility that can assess the relative costs and benefits, and either accelerate or decelerate the pace of reduction in future planning cycles as required.

3.1.1.4 Strategic Resource Zone deficit

For the final plan, later in the planning horizon we are faced with a very small baseline supply-demand deficit in our Strategic Resource Zone (and under different scenarios this also has the potential to be larger). Many of the most cost beneficial options that can be selected are leakage management options, and reducing leakage is one of the best solutions in managing this. Even retaining the original leakage reductions proposed in the draft plan under that strategic choice would have addressed this deficit for the final planning position. However, this shows the benefit of leakage reductions in supporting a robust supply-demand balance that can deal with change over time.

[30] Three year average total leakage, based on reported total leakage for 2015/16 to 2017/18

3.1.2 Decision making and the strategy to deliver reductions in leakage

The decision was made to reduce leakage by 20% by 2024/25 and the rationale behind this decision is set out in the previous section, 3.1.1. This section covers the approach to selecting the specific options to deliver these reductions as part of our preferred plan.

Our approach has used a combination of AISC ranking and EBSD modelling to determine the most cost effective leakage programme over the 2020 to 2045 planning period. Our leakage options included a wide range of solutions, from current tried and tested methods, third party options, and new and innovative technologies that are currently under trial or in the early phases of deployment.

Initially, using the modelled approach alone, this did not provide a balanced programme in terms of risk and innovation. This biased the programme to potentially cheaper, yet unproven or potentially reliable options early in the planning period. As defined in the draft plan, we therefore created a portfolio that was balanced (based on available evidence then available) over time to ensure an increasing proportion of innovation following initial pilots and more limited implementation prior to wider roll-out. Subsequently, for the final plan, further investigation has allowed us to bring innovations forward into the earlier part of the planning period.

One of the most promising developments seen across the industry and from our own current trials, has been the availability of permanent acoustic and noise logging technology. The deployment of this technology can significantly reduce the awareness time of leaks, and rather than carry out an intervention or sweep of entire DMAs, can provide localisation and in some cases pinpointing of leaks that can then be followed up and repaired. This is seen as an essential enabler in a step forward to being able to achieve lower levels of leakage. There is more confidence in this technology, and particularly where it can also be used in conjunction with remote sensing and imagery collected from satellites to provide hotspots.

There are other innovative and third party options that have significant potential benefit, particularly in relation to customer side leakage, however, there is such a high level of uncertainty, these options require further trials and a more moderate roll out in the next few years, to reduce the uncertainty and potentially reduce costs by the next round of water resources planning. We have, therefore, made some decisions with the aim of:

- Producing a leakage reduction programme that was affordable and acceptable to customers;
- Balancing innovation and confidence in delivery in the short term, by incorporating options that are tried and tested, as well as new technology/innovations that carry more uncertainty, but are necessary to drive longer term efficiencies;
- Utilising third party options that have significant longer term potential, but need to be rolled out in a controlled way to manage the risk to customers as well as ensuring deliverability; and
- Setting out a programme that can drive continuous improvement.

We have the opportunity to work closely with third-party suppliers to further develop and trial these options. We should of course recognise that by 2025 some of the newer approaches may already have been displaced by technologies that are yet to be invented; this is natural for a long-term strategic planning process like the Water Resources Management Plan. Our future forecasts will be reviewed fully in each planning round.

It is important to point out that any third-party contributions implemented in the future will be subject to an appropriate procurement process[31], taking account of any legislative requirements. This applies to any trials or pilot studies that fall within the legal requirements. There is significant focus on innovation and the involvement of specialist third parties.

Therefore, we have decided to split the leakage programme into two distinct phases, as also illustrated in Figure 6 below:

- In the first five years, from 2020 to 2025, there is a balance between options that we know are proven, whilst driving innovative options into the plan; and

[31] As part of a bid assessment framework. We will be submitting to Ofwat our proposed approach as part of our Business Plan.

- Beyond 2025, we have included options that are less cost-beneficial, or are cost beneficial, but more uncertain and require time to do further trials and investigations.

2020-25 **91 Ml/d reduction** More focus on innovation in AMP7, including several trials, but retaining the reliable find/fix and pressure optimisation options	• **Reduce leakage and improve water efficiency by identifying customer side leakage and use patterns (trials ongoing)**	**2 Ml/d** *(third party)*
	• **Leakage reduction through additional find/fix using acoustic loggers**	**50 Ml/d** *(UU & third party)*
	• **Leakage reduction through additional find/fix and pressure optimisation**	**28 Ml/d** *(UU)*
	• **Proactive monitoring of household meters to identify and fix supply pipe leaks**	**4 Ml/d** *(UU & third party)*
	• **Temporary logging of large customers**	**1 Ml/d** *(UU)*
	• **Splitting DMAs**	**2 Ml/d** *(UU)*
	• **Splitting upstream tiles**	**4 Ml/d** *(UU)*
2025-45 **99 Ml/d reduction** Using the findings from AMP7 and further innovation	• **Reduce leakage and improve water efficiency by identifying customer side leakage and use patterns (trials ongoing)**	**75 Ml/d** *(third party)*
	• **Leakage reduction through additional find/fix and pressure optimisation**	**24 Ml/d** *(third party)*

Figure 6 Details of our proposed leakage reduction programme

The decision making process for the leakage programme has been taken through a combination of:

- Consideration of a wide range of factors that justified the proposed 20% reduction from baseline;
- AISC ranking and EBSD modelling to assess options initially; and
- Refinement of the programme to balance current tried and tested methods, with new and innovative approaches, considering deliverability and reliability in the short term with the need to innovate, to ensure the right balance of options is selected.

The two elements of this approach, firstly the justification for setting the proposed target over time, and secondly the specific options selected in order to deliver the reduction, have both been decisions that were taken through our internal governance process. Customer engagement and valuations has been used to shape the level of reduction. Stakeholder consultation also challenged us to be more innovative, therefore we have factored this into our decision making. Table 12 below summarises the specific options selected in the Strategic Resource Zone, with a likely option start date. The same table presented in the previous version of this report is shown in Appendix D.

Table 12 Strategic Resource Zone leakage reduction options considered to deliver proposed WRMP19 leakage reduction (AMP7 covers 2020/21 to 2024/25, AMP8 covers 2025/26 to 2029/30, AMP9 covers 2030/31 to 2034/35, AMP10 covers 2035/36 to 2039/40 and AMP11 covers 2040/41 to 2044/45)

Focus	Option reference	Option short name	Leakage reduction (Ml/d)	AISC (pence per cubic metre)	Likely option start year	Rationale for programme choice
Reliability, which is key for the supply-demand balance in the shorter term, with further focus on innovation to deliver increased leakage reduction	**WR500a**	LEA_SRZ REDUCTION_1	10	14.0	2020/21	Selected for reliability to deliver AMP7 commitment
	WR500b	LEA_SRZ REDUCTION_2	10	18.4	2020/21	Selected for reliability to deliver AMP7 commitment
	WR500c	LEA_SRZ REDUCTION_3	8	23.9	2020/21	Selected for reliability to deliver AMP7 commitment
	WR500f	LEA_SRZ REDUCTION_6	5	14.9	2020/21	Innovative technique to deliver AMP7 commitment
	WR500g	LEA_SRZ REDUCTION_7	5	25.9	2020/21	Innovative technique to deliver AMP7 commitment
	WR500h	LEA_SRZ REDUCTION_8	10	34.8	2020/21	Innovative technique to deliver AMP7 commitment
	WR500i	LEA_SRZ REDUCTION_9	10	50.1	2020/21	Innovative technique to deliver AMP7 commitment
	WR500j	LEA_SRZ REDUCTION_10	10	61.2	2020/21	Innovative technique to deliver AMP7 commitment
	WR907e	LEA_THIRD PARTY_SRZ_32	2	(1.4)	2020/21	Pilot to test reliability for future delivery
	WR500k	LEA_SRZ REDUCTION_11	5	66.0	2020/21	Potential to help deliver AMP7 commitment
	WR503	LEA_HH_SUPPLY PIPE	4	(6.3)	2020/21	Potentially low reliability, but can be developed to contribute to AMP7 commitment
	WR514	LEA_SRZ_TEMPORARY LOGGING	1	(3.2)	2020/21	Small benefit, but can contribute to AMP7 commitment
	WR515	LEA_SRZ_DMA SPLITTING	2	4.1	2020/21	High level of uncertainty, but can be developed to contribute to AMP7 commitment
	WR517	LEA_SRZ_TILE SPLITTING	4	10.4	2020/21	High level of uncertainty, but can be developed to contribute to AMP7 commitment
	WR912	LEA_THIRD PARTY_SRZ_38	5	(5.7)	2020/21	Can be developed to contribute to AMP7 commitment
Use the findings from AMP7 to deploy further (or wider) innovation	**WR907f**	LEA_THIRD PARTY_SRZ_33	~10	(1.6)	2025/26	Will contribute to AMP8 commitment, if found to be reliable in AMP7 pilot
	WR914	LEA_THIRD PARTY_SRZ_39	4	9.6	2025/26	High level of uncertainty, but can be developed to contribute to AMP8 commitment
	WR500d	LEA_SRZ REDUCTION_4	10	31.5	2025/26	Will contribute to future commitments
	WR500e	LEA_SRZ REDUCTION_5	10	43.6	2030/31	Will contribute to future commitments
	WR907d	LEA_THIRD PARTY_SRZ_34	~54	(3.2)	2030/31	Will contribute to future commitment, if found to be reliable in AMP7 pilot
	WR907g	LEA_THIRD PARTY_SRZ_34	~10	(1.6)	2030/31	Will contribute to future commitment, if found to be reliable in AMP7 pilot

3.2 Improve the stated level of service for drought permits and orders to augment supplies

At WRMP15, we committed to undertake further work to understand how an improved level of service for implementing drought permits could be delivered beyond 2020. Since then we have carried out further customer research and consultation on specific proposals for WRMP19. As documented in our *Draft WRMP19* main report, moving to an improved level of service for drought permits and orders to augment supplies is supported by stakeholders, and customers have shown some willingness to pay, albeit not as a priority area in its own right[32].

Section 6.1.7 of our *Final WRMP19 Technical Report - Supply forecasting* covers our assessment of different levels of service for drought permits, as well as those for temporary use bans[33]. Section 3.4 of our *Final WRMP19 Technical Report - Customer and stakeholder engagement* shows the value customers placed on the frequency of drought permits and this value is presented in Table 13 below. From this same research, there was insufficient willingness to pay to improve the stated level of service for temporary use bans. This was consistent with customer views from our more qualitative research and, therefore, improving the level of service for temporary use bans was not considered as a strategic choice.

Table 13 The value customers placed on the frequency of drought permits

Activity	Customer valuation from WRMP19 programme choice experiment (pence)
1 year change in frequency of drought permits	3p

Table 14 uses the value from Table 13 to show the costs and benefits of different levels of service for drought permits and drought orders to augment supply.

Table 14 Costs and benefits of different levels of service for drought permits and drought orders to augment supply

Level of service for the implementation of drought permits	Water available for use impact	Maximum annual increase in bill (pence)	Customer valuation from WRMP19 programme choice experiment (pence)	Cost beneficial
1 in 10 or a 10% chance in any year (deterioration)	Not considered as no customer or stakeholder support to deteriorate			
1 in 20 or a 5% chance in any year (current level)	0 Ml/d	0p	0p	N/A
1 in 40 or a 2.5% chance in any year (enhancement)	10 Ml/d[34]	0p (can be delivered by our proposed leakage reduction programme, discussed in Section 3.1)	60p	Yes

Although this is not a key priority for customers in its own right in the context of the wider programme and affordability, based on the cost benefit and accounting for our proposed leakage reduction programme, we are proposing to improve the stated level of service for drought permits and orders to augment supplies to 1 in 40 (or a 2.5% chance in any year) from 2025.

It should be noted that whilst the formal stated minimum level of service is proposed to be changed at the end of the next 5-year planning period, customers and stakeholders would essentially be benefitting from reduced leakage reductions before this time. The level of service is a stated minimum level, and in practice, performance should at least be as good as this level, as detailed further in *Final WRMP19 Technical Report - Supply forecasting*. After the initial step change in level of service by 2025, the supply-demand balance position and level of service may then be considered further in the next planning round.

For non-essential use bans, we are able to improve the stated expected frequency from no more than 1 in 35 years on average to no more than 1 in 80 years (moving from 2.9% to 1.25% annual average risk), reflecting the point at

[32] There was a slight preference for less frequent drought permits (1 in 24 years on average)
[33] Previously "hosepipe bans"
[34] This is not water available for use in a conventional sense, but an estimate of lost water to preserve stable resilience

which we would expect these to be implemented from our analysis. This is simply due to gaining a much better understanding of our actual drought resilience from our sophisticated new tools and techniques. This will not result in an improvement to the actual level of service experienced by customers.

We also confirmed that our expected frequency of implementing emergency drought orders is better than Defra's reference level of 1 in 200 years (0.5% annual risk). This does not constitute an improvement in the level of service statement as such, but adds context to our existing position that they are unacceptable, even in extreme droughts. We explored further improving our drought resilience, but ultimately it is already at a high level and there is no customer appetite to invest specifically to further improve this, albeit this is still achieved as a supplementary benefit of leakage reductions and customers do not want to see deterioration in service (for example, under potential future water trading). All of this analysis is described in Section 6.3 of our *Final WRMP19* main report.

3.3 Increase the resilience of our supply system to non-drought hazards

For the first time, our WRMP covers an assessment of water supply system resilience. This strategic choice relates to the largest water supply system risk identified through this assessment, termed "Manchester and Pennines Resilience" and the specific choice is around the level and pace of risk reduction. The solutions to reduce or mitigate the risk comprised either rebuilding or repairing aqueduct sections, new water treatment works for operational use, or some new assets to provide redundancy for outages or failures. The options appraisal work, as well as the preferred solution, is reported in our *Final WRMP19 Technical Report - Water supply resilience (*Appendix A), and summarised in Section 6.4 of the *Final WRMP19* main report. Customer and stakeholder engagement confirmed the need to reduce risk significantly from current levels.

3.4 Continue to explore national water trading from our Strategic Resource Zone

This strategic choice was the key reason for us using extended methods, although it has been used to understand the benefits of some of our other strategic choices, and is in part driven by a national need to explore water trading. A key role of the extended methods is to ensure that customers and the environment are protected.

As explained in Section 6.5 of our *Final WRMP19* main report, this strategic choice relates to national water trading. However, as described in that report, potential importing companies have not selected imports from the North West in their preferred plans with the core 25-year period of the planning horizon (which defines our 'needs' in this plan, albeit our plans are tested out to the 2080s). Therefore, water trading cannot be taken forward under this strategic choice to form part of the preferred plan. Our strategy to facilitate a future trade has been retained within an adaptive pathway (see Section 8 of our *Final WRMP19* main report), which could form a future preferred plan if water trading was subsequently required in future. The pathway sets out how customers and the environment are protected under a future export. We will continue to work with others on water trading beyond WRMP19 towards the WRMP24 planning cycle.

Section **4** of this technical report covers our assessment of national water trading using extended methods as part of the pathway approach.

4. Extended methods

As discussed in Section 7.2 of our *Final WRMP19* main report, to aid in decisions around national water trading and other strategic choices, we have used a sophisticated options appraisal process (known as "extended methods"). The key aim of which is to ensure that customers and the environment are protected under any potential water trade.

The extended methods process, created in conjunction with one of our service providers, Atkins, has allowed us to understand the performance of the Strategic Resource Zone, via certain metrics (documented further in Section 4.4), and assess the impact of a national water trade on those metrics. Figure 7 provides an overview of the extended methods process used for selecting a portfolio of for the water trading pathway. The lighter shaded cell also provides an indication of how the process might evolve for the next Water Resources Management Plan in 2024.

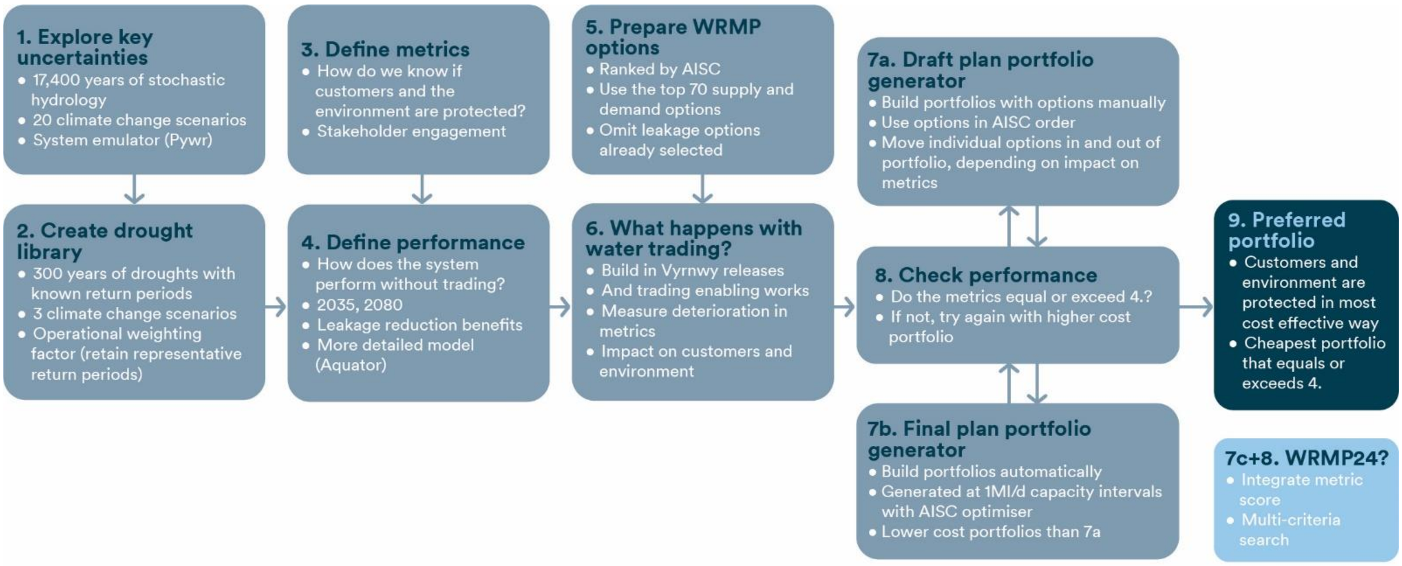

Figure 7 Overview of extended methods process

4.1 Weather and flow generation (climate change and stochastic modelling)

As explained in Appendix B of our *Final WRMP19 Technical Report - Supply forecasting*, Atkins has created 17,400 years of stochastic[35] inflows for the Strategic Resource Zone. Stochastic inflows represent statistically plausible versions of historic conditions, as they are based on historical weather patterns, but contain more extreme events due to the volume of data (i.e. we can sample the tails of the distribution).

As part of the climate change assessment for WRMP19, HR Wallingford created 100 sets of climate change factors, which were a sub-sample of the 10,000 UKCP09 climate projections[36] for the 2080s, under medium emissions. A sub-set of 20 of these factors were selected for the climate change assessment by testing with a simplified model of the Strategic Resource Zone, built by Atkins in Pywr water resources software. This work is described in our *Final WRMP19 Technical Report - Supply forecasting*.

For extended methods, three of these 20 climate change scenarios were selected to represent the circa. 50th (referred to as "CCA"), 75th (referred to as "CCB") and 90th (referred to as "CCC") percentiles of climate change impact, and the factors were used to perturb the stochastic flows. This enabled the assessment to take place with a broad range of climate change impacts, but allowed the assessment of system performance in droughts more severe than those in the historic record.

As part of a joint project with Thames Water, Atkins also carried out a piece of work to match the stochastic sequences for the South East of England, with those for our region. This was used to create utilisation sequences for

[35] Synthetically generated hydrology used to explore a wide range of droughts; explained in our *Final WRMP19 Technical Report - supply forecasting*
[36] http://ukclimateprojections.metoffice.gov.uk/

water trading that matched our stochastic inflow record, allowing us to thoroughly test our system in a water trading scenario (i.e. the adaptive pathway).

4.2 Uncertainty exploration and drought library selection (Robust Decision Making principles)

As the Strategic Resource Zone Aquator™ model is large and complex, it would have been practically infeasible to run full stochastic sequences through on multiple occasions[37]. To assess the severity of events in the perturbed stochastic sequence, a simplified model of the Strategic Resource Zone was created in Pywr. This system uses cloud computing[38] and can run enormous data sets in a short period of time. Each of the 20 sets of climate change perturbed stochastic flows[39] was run through the model at 26 demand steps. The system response in each run was assessed by emergency storage failures (see Figure 8 for an example of this). By counting the number of failure years at each demand a return period could be placed on each failure year (e.g. if there was a single failure in the whole run, then that event would have a return period of 17,400 years). By allocating a return period to each year it was possible to select the required number of droughts with the specified severity.

2080s	Demand																									
UKCP09_ID	1600	1625	1650	1675	1700	1725	1750	1775	1800	1825	1850	1875	1900	1925	1950	1975	2000	2025	2050	2075	2100	2125	2150	2175	2200	2225
3413	644	446	285	205	146	99	71	48	33	24	15	10	7	6	4	3	3	2	2	2	2	1	1	1	1	1
1952	870	644	512	370	232	163	128	94	70	56	41	31	24	18	14	12	9	7	6	5	4	4	3	3	2	2
6035	669	527	405	268	191	133	95	66	43	32	22	16	11	8	6	5	4	3	3	2	2	2	2	2	1	1
7916	2486	1933	1582	1450	1024	696	378	245	147	86	54	36	25	17	13	10	8	6	5	4	4	3	3	2	2	2
6050	3480	2900	1243	791	644	527	341	249	145	91	64	45	33	24	19	15	11	9	7	6	5	4	4	3	3	2
9942	1933	1582	1450	1088	725	580	395	252	166	121	87	65	50	38	30	23	18	15	12	9	7	6	5	4	4	3
8937	2900	2175	1933	1243	1088	696	470	290	198	119	83	61	45	34	25	19	15	12	9	8	6	5	4	4	3	3
6923	5800	3480	2900	2175	1933	1160	791	405	300	166	107	67	47	33	23	17	13	10	8	6	5	4	4	3	3	2
864	2900	1933	1740	1450	1024	669	458	355	238	146	98	68	52	39	30	23	18	14	11	9	7	6	5	4	3	3
8026	4350	2900	1933	1582	1160	967	621	483	378	235	158	116	85	65	49	38	30	24	18	15	12	9	7	6	5	4
6252	3480	2900	1933	1338	1160	967	644	414	295	183	123	84	60	46	36	28	21	17	13	11	8	7	6	5	4	3
6341	5800	4350	4350	3480	2486	1450	1024	757	483	268	178	125	81	57	43	34	25	19	15	12	9	8	6	5	4	4
9474	4350	4350	3480	2486	2175	1338	1024	644	544	300	196	137	93	67	49	38	29	22	17	14	11	9	7	6	5	4
6622	17400	8700	8700	8700	5800	2900	2900	1160	916	696	378	295	207	139	98	70	53	40	30	24	19	15	11	9	7	6
941	17400	17400	8700	8700	8700	5800	4350	1933	1024	870	600	370	229	166	117	88	66	48	37	29	22	17	14	11	8	7
9543	17400	17400	8700	8700	8700	5800	5800	2900	1243	791	580	355	268	193	139	104	75	60	46	34	25	20	16	13	10	8
6962	17400	8700	8700	8700	8700	8700	5800	2486	1450	967	512	285	196	132	102	76	56	42	33	25	19	15	12	9	7	6
9985	17400	17400	17400	8700	8700	8700	8700	4350	2175	1740	829	644	370	295	215	144	110	83	61	45	33	25	20	16	13	10
3372	inf	17400	17400	17400	8700	8700	8700	5800	2900	1450	1243	967	696	497	290	205	146	108	77	60	43	32	24	19	15	12
5231	inf	inf	inf	inf	17400	17400	17400	17400	17400	17400	8700	5800	2900	2486	1933	1450	967	621	424	281	187	139	97	69	51	38

Figure 8 Baseline breaches of reservoir emergency storage simulated with a range of demands (shown across the top) and 2080 climate change scenarios (shown down the left hand side)

Drought libraries containing a fixed number of events of varying severity (see Table 15) were created, to limit the run time and allow multiple configurations and portfolios of options to be tested. Each drought was given a two year "warm up" period and a one year "cool down" period. The selected hydrology was then spliced together with other randomly selected periods to create a carefully constructed dataset for Scenario Simulation in Aquator™. This was a very innovative approach and, to our knowledge, has not been done elsewhere as part of WRMP19.

[37] Each 17,400 year model run would take about a week.
[38] Cloud computing is the practice of using a network of remote servers to store, manage, and process data, rather than a local server or a personal computer.
[39] In line with the findings of the climate change vulnerability and modelling, described in our *Final WRMP19 Technical Report - Supply forecasting*, groundwater sources have a low vulnerability to climate change and, therefore, source yields have not been adjusted for climate change impacts

Table 15 Severity and number of events in each drought library[40]

Return period (1 in X years)	Number of events in drought library
1000	3
500	3
250	9
100	9
50	9
30	9
20	12
10	12

4.3 Detailed Scenario Simulation in Aquator™ water resources model

As documented in our *Final WRMP19 Technical Report - Supply forecasting*, the Strategic Resource Zone Aquator™ model is complex, but provides the best way to assess system response, as it contains all of the key constraints in the real system. It was used to test system response under the conditions represented by the drought libraries, in scenarios representing different strategic choices (e.g. with water trading taking place) and with different portfolios of options.

A number of changes were made to the Strategic Resource Zone base model to make it suitable for portfolio testing in extended methods. These changes included:

- Allowing the use of emergency storage[41], as we would expect to use emergency storage in droughts more severe than those experienced historically; and
- Annual demand variation, depending whether it was a selected "dry year" (1 in 20 year frequency or less) or not. Dry years had "dry year" demand and other years has "average year" demand (Table 16).

4.3.1 Portfolio creation and selection

As discussed in Section 2.3 and 2.4, portfolios (abbreviated below to "PF", e.g. PF1 would be portfolio 1) are sets of options designed to address a strategic choice or more typically a combination of strategic choices in an alternative plan. The options appraisal process aims to deliver the best value set of options for each case tested.

A key element considered when generating a portfolio is cost effectiveness and the core methods of AISC ranking and EBSD modelling, described in Section 2.2, were utilised to ensure that the portfolios tested with extended methods were the most cost effective for a given capacity. EBSD modelling was used initially to understand which options were being chosen at varying supply-demand deficit levels, but as extended methods became more about protecting system performance (via the metrics shown in 4.4), and was not defined by a supply-demand balance need, AISC ranking became a direct input to the options appraisal process. The 70 options with the lowest AISC were built into the Scenario Simulation model in Aquator™ and, through the modelling process, we discovered how the locations and size of the different options influenced the system performance, via the metrics (Table 17).

EBSD modelling was also used to help schedule the options in a portfolio from extended methods, based on the earliest start year (using the estimated amount of time needed to investigate and implement each option). It's worth noting that cost effective leakage options already formed part of the proposed leakage reduction programme (see Section 3.1) and, therefore, were pre-selected in extended methods and reflected via reduced demand for water. Cost effective water efficiency options were reflected in extended methods in the same way. However, as the benefit of water efficiency options decays over time[42], we used the average benefit over the planning period.

[40] As the number of droughts in the library exceeded the naturally occurring frequency, operational weighting factors were used to prevent the skewing of the statistical results produced by the over representation of severe events. This methodology allowed statistics to be calculated that represented the results of testing with a longer record that would have contained the severities of droughts described, but in a much more efficient way.

[41] As described in our *Final WRMP19 Technical Report - Supply forecasting*, this is a "reserve water storage capacity aimed at accommodating the operational uncertainty for the duration of a particular drought".

[42] As discussed in *Final WRMP19 Technical Report - Demand for water*, we apply a decay rate or half-life of two and a half years to represent factors, such as the deterioration in water efficiency products over time.

4.3.2 Extended methods time slices

In terms of temporal coherence, two key "time slices" have been used for the modelling of national water trading for extended methods:

- The 2030s was selected as the earliest potential timing for a national water trade[43], a key strategic choice[44], with any options being developed in the period from 2024/25 onwards; and
- The 2080s was selected to align to our furthest reaching calculated climate change impacts. This view helps to ensure best value for customers over the longer term, helping us to understand the impact of uncertainty on our plans, useful when considering the time it takes to develop major infrastructure.

Table 16 shows the demand for water to be used to represent the two time slices. As different percentiles of climate change are being tested explicitly in extended methods, climate change headroom has not been included to ensure there is no double counting of uncertainty. There is significant uncertainty in our demand forecast for the 2080s.

Table 16 Demands for extended methods modelling

Resource Zone	Demand Adjustment Applied	Demand in the 2030s (Ml/d)	Demand in the 2080s (Ml/d)	Raw water and process losses (Ml/d)	Outage allowance (Ml/d)	Target headroom not inc. climate change in the 2030s (Ml/d)	Target headroom not inc. climate change in the 2080s (Ml/d)	Demand in the 2030s for extended methods (Ml/d)	Demand in the 2080s for extended methods (Ml/d)
Strategic (baseline)	"Average year"	1,621	1,671	42	101	52	53	1,816	1,867
Strategic (baseline)	"Dry year"	1,679	1,741	42	101	52	53	1,874	1,937
Strategic (with leakage reduction[45])	"Average year"	1,506	1,466	42	101	52	53	1,701	1,662
Strategic (with leakage reduction[45])	"Dry year"	1,564	1,535	42	101	52	53	1,759	1,731

Table 29 in Appendix B shows a full list of the scenarios tested in extended methods, representing the leakage reduction at the different time slices, the different demand levels and the different setups of national water trading that have been explored.

[43] Our assessment is based on 2034/35, however, it may be considered as representative of a trade occurring at any point in the 2030s; this was the agreed working assumption during WRMP19 development. It is unlikely that any trade will be required before this date based on discussions. Thames Water's latest scenarios at the time of publication show the earliest date of scheme selection to be in 2039, which is very close to the 2035 assumed date within the draft plan. The difference is not material for this adaptive pathway assessment. If the trade is at a later date, defined by other Water Resources Management Plans and/or subsequent work, we will reassess our plans accordingly in future.

[44] In line with the outcomes of the Water resources long-term planning framework 2015-2065 (Water UK, September 2016)

[45] Based on the final WRMP19 proposed leakage reduction, this would be a 133 Ml/d leakage reduction at 2034/35, followed by increased reductions of 190 Ml/d by 2044/45, which then continue by 5 Ml/d per AMP cycle to 2079/80

4.4 System performance evaluation (via metrics)

Metrics help us to ensure that we are achieving the overarching aims set out at the start of Section 3. Table 17 documents our WRMP19 metrics, developed with input from customers[46], regulators[47] and other stakeholders[48]. The results from our extended methods modelling were simplified by placing them into performance bands, allowing an easy visual comparison.

Table 17 Metrics for WRMP19

Metric type	Initial metric category	Metric	Why is this a metric?	Calculation of metric	Banding used to present metric
Primary	Customer	Change in the likelihood of temporary use bans	This is measure of the frequency of the implementation of temporary use bans, previously "hosepipe bans", the impact of which directly affects customers.	Calculate the total number of temporary use ban events expected in a 25 year period and measure the percentage change in these.	<2% change equates to no impact 2% to 6% = +/- 6% to 10% = ++/-- >10% = +++/---
Primary	Customer	Change in drought resilience	This is a measure of the risk of drought that customers are under, the impact of which directly affects customers	Calculate storage remaining at annual minima. Convert this into a 'number of days remaining' based on emergency storage equating to 20 days of supply. Take first percentile of results (roughly equivalent to a 1:100 year event or 1% annual chance).	<2 days = no impact 2 to 5 days = +/- 5 to 10 days = ++/-- > 10 days = +++/---
Primary	Environment	Change in river flows and implementation length of drought permits	This is a measure of the length of time drought permits are implemented for, the impact of which directly affects the environment.	Calculate both as a value per annum and calculate the weighted average percentage change.	River flows below prescribed flow: <1% = no impact 1 to 5% = +/- 5 to 10% = ++/-- > 10% = +++/--- Drought permits: <5% change equates to no impact 5% to 10% = +/- 10% to 20% = ++/-- >20% = +++/---
Contributory	Environment	Change in abstraction from environmentally sensitive groundwater sources	This is a measure of the potential impact on the amount of water abstracted from several Water Framework Directive (WFD) sensitive groundwater sources.	Total abstraction divided by number of days, expressed as a percentage change.	<1% change equates to no impact 1% to 5% = +/- 5% to 10% = ++/-- >10% = +++/---
Contributory	Customer	Change in spill from reservoirs	A key concern for our customers and stakeholders, while a full flooding impact assessment is being carried out separately as part of our resilience review, this spill metric allows us to understand if our actions are likely to lead to an increase (or decrease) in spill from reservoirs. Conversely, greater spill, and spill variability, can benefit downstream habitats.	Generate annual maximum for each year, then use percentile calculator to estimate 99th percentile. Change expressed as a percentage.	<1% change equates to no impact 1% to 5% = +/- 5% to 10% = ++/-- >10% = +++/---
Contributory	Customer	Climate change resilience – change in the likelihood of temporary use bans	Helps us understand if our primary metric of "change in the likelihood of temporary use bans" is impacted under different potential climate change scenarios.	As main metric, but compare CCA to CCA, CCB to CCB and CCC to CCC for baseline and with options scenarios.	Highlight if there is a change in band as a result of climate change. The worst impact will be shown.
Contributory	Customer	Climate change resilience – change in drought resilience	Helps us understand if our primary metric of "change in drought resilience" is impacted under different potential climate change scenarios.	As main metric, but compare CCA to CCA, CCB to CCB and CCC to CCC for baseline and with options scenarios.	Highlight if there is a change in band as a result of climate change. The worst impact will be shown.

[46] Through key priorities from our customer research

[47] Through early engagement with the Environment Agency, Natural Resources Wales (NRW), Ofwat and the Drinking Water Inspectorate (DWI).

[48] Via our WRMP19 Technical Stakeholder Group (TSG)

5. Preferred plan

The section sets out our preferred plan for WRMP19, as the most cost effective and sustainable long-term solution, with the alternatives we consulted upon shown in Appendix D. It also shows how we'll deal with national water trading, via a trading and non-trading pathway, and how we've assessed the benefits of leakage reduction and investment in resilience. The full narrative can be found in Section 7 of our *Final WRMP19* main report.

5.1 Deciding on a preferred plan

The section uses information from Section 3 and the findings from extended methods, documented in Section 4, to show why leakage reduction and investment to improve resilience (previously referred to as "Alternative Plan 3") is now our preferred plan. We still wish to pursue water trading (referred to as "Alternative Plan 4" in our *Draft WRMP19*, constituting "Alternative Plan 3" and national water trading) as a way of meeting a national need. However, unfortunately the trade from Lake Vyrnwy was not selected by Thames Water as part of their preferred plan. Therefore, we have now removed national water trading from our preferred plan, to reflect their decision and maintain consistency between our WRMP. Therefore, national water trading now forms the basis of a trading adaptive pathway, described further in Section 6.

5.1.1 Benefits of leakage reduction

Extended methods was also used to understand the wider benefits of leakage reduction. The impact on system performance, demonstrated by the metrics shown in Section 4.4, is shown in Table 18.

Table 18 Benefits of the leakage reduction by 2034/35 compared to the baseline (previously referred to as Alternative Plan 1 in our Draft WRMP19), as assessed in extended methods

	Baseline	Leakage reduction proposed in our Draft WRMP19	Leakage reduction proposed in our Final WRMP19
Scenario (see Appendix B for explanation)	2035_Base	2035_L60	2035_L133
Cost (NPV in £m with environmental and social costs)	0	46.7	302.6
Change in the likelihood of temporary use bans	NSC	+++	+++
Change in drought resilience	NSC	+	++
Change in river flows and implementation length of drought permits	NSC	++	+++
Climate change resilience – change in the likelihood of temporary use bans	NSC	NSC	+++
Climate change resilience – change in drought resilience	NSC	NSC	++
Change in abstraction from environmentally sensitive groundwater sources	NSC	+	+++
Change in spill from reservoirs	NSC	-	-

The benefits in the customer and environment metrics are clearly shown, with a positive impact on the likelihood of temporary use bans and drought resilience, as well as the implementation length of drought permits and the reduction in abstraction from environmentally sensitive groundwater sources. Benefits to the metrics increase further with the increased leakage reductions at final plan, benefitting the drought permit and drought resilience primary metrics.

5.2 Our preferred plan

As outlined in this technical report and the *Final WRMP19* main report, we have chosen the preferred plan using standard industry methods that include consideration of technical feasibility, financial costs and benefits, and quantified impacts on the environment and community, taking into account the findings of the SEA, HRA and WFD Assessment (Section 5.2.4), as well as input from key stakeholders.

In our *Draft WRMP19* consultation, we proposed four alternative plans as outlined in Appendix D. In simple terms, leakage reduction, investment to improve resilience and further exploration of national water trading (referred to as "Alternative Plan 4") was selected as our preferred plan, because it contained all of the strategic choices we'd proposed to address customer and stakeholder views. However, as stated above, unfortunately the trade from Lake Vyrnwy was not selected by Thames Water as part of their preferred plan. Therefore, we have now removed water trading from our preferred plan to reflect their decision, and maintain consistency between our WRMP. We are still planning to address pressing supply system resilience needs, and meet customer and regulatory aspirations on leakage reduction, and at the same time provide environmental benefits and allow us to improve our level of service for drought permits in 2025.

National water trading now forms the basis of a trading adaptive pathway (essentially a detailed scenario) and, in order to select options for this pathway, we developed a sophisticated "extended methods" approach, as outlined in this technical report and in Section 7.2 of the *Final WRMP19* main report. Its principal objective was to help ensure that customers and the environment are protected in the event of water trading. In summary, portfolios of options are generated and optimised on the basis of a range of performance metrics relating to cost, customers (including resilience) and the environment; the preferred plan includes the most optimal set of options. Those portfolios rejected as part of the process either did not meet the objective to protect customers and the environment, or did not represent the lowest cost way to achieve this.

Overall, our comprehensive option identification and appraisal process means that, from a very large pool of options, only the most applicable ones have been selected in the preferred plan. This is critical to ensuring that the plan represents the most cost effective and sustainable solution in the long-term. The specific options to deliver the above plan are shown in Table 19.

Table 19 Preferred plan options

	AMP7	AMP8	AMP9	AMP10	AMP11
Preferred plan	**~91 Ml/d further leakage reduction** WR500a to c (28 Ml/d), WR500f to k (45 Ml/d), WR503 (4 Ml/d), WR514 (1 Ml/d), WR515 (2 Ml/d), WR517 (4 Ml/d) 3rd party pilots WR907e (2 Ml/d), WR912 (5 Ml/d) **Manchester and Pennines Resilience** Solution D "Rebuild all tunnel sections"	**~21 Ml/d further leakage reduction** WR500d (~10 Ml/d) 3rd party WR907f (~7 Ml/d), WR914 (4 Ml/d) **Manchester and Pennines Resilience** Solution D "Rebuild all tunnel sections"	**~21 Ml/d further leakage reduction** WR500e (~3 Ml/d) 3rd party WR907d (~15 Ml/d), WR907f (~1 Ml/d) WR907g (~3 Ml/d)	**~28 Ml/d further leakage reduction** WR500e (~3 Ml/d) 3rd party WR907d (~18 Ml/d), WR907f (~3 Ml/d) WR907g (~4 Ml/d)	**~28 Ml/d further leakage reduction** WR500e (~3 Ml/d) 3rd party WR907d (~21 Ml/d), WR907g (~4 Ml/d)

For more detail on each specific option, including high level scope, please refer to our *Final WRMP19 Technical Report - Options identification*.

5.2.1 Our plan using core methods

As discussed in Section 2.5, we are now forecasting a very small baseline deficit in our Strategic Resource Zone between 2040/41 to 2044/45. We carried out an EBSD model run to resolve the deficit and all the options selected were leakage options that are already included in our preferred plan (WR503, WR907d, WR907e, WR907f, WR907g, WR912, and WR503).

5.2.2 Greenhouse gas emissions

Environmental (including carbon) and social costs have been considered throughout the options appraisal process. This section aims to report the greenhouse gas emissions that could arise from our preferred and alternative plans, in line with The Water Resources Management Plan (England) Direction 2017. Table 20 and Figure 9 summarise the greenhouse gas emissions from our preferred plan in carbon dioxide equivalent (CO_2e). Table 21 provides detailed data on the emissions from each measure.

There is a sharp reduction in operational greenhouse gas emissions following the shift to buy renewably generated electricity with zero greenhouse gas emissions. The remaining emissions are associated with use of fuels such as gas, diesel and kerosene for pumping, treatment and transport activities when electricity is not applicable because of location or circumstances. Remaining emissions therefore are not proportional to the overall water production and will not reduce noticeably from leakage reduction.

Table 20 Greenhouse gas emissions from our preferred plan

	Construction or implementation related carbon, including embedded carbon (total tonnes CO_2e)	Operation related carbon (average tonnes CO_2e per year over the planning period)
Impact of enhanced leakage reduction	24,797	0
Impact of increased resilience to other hazards	951,285	0
Impact of enhanced leakage reduction and increased resilience to other hazards	976,082	0

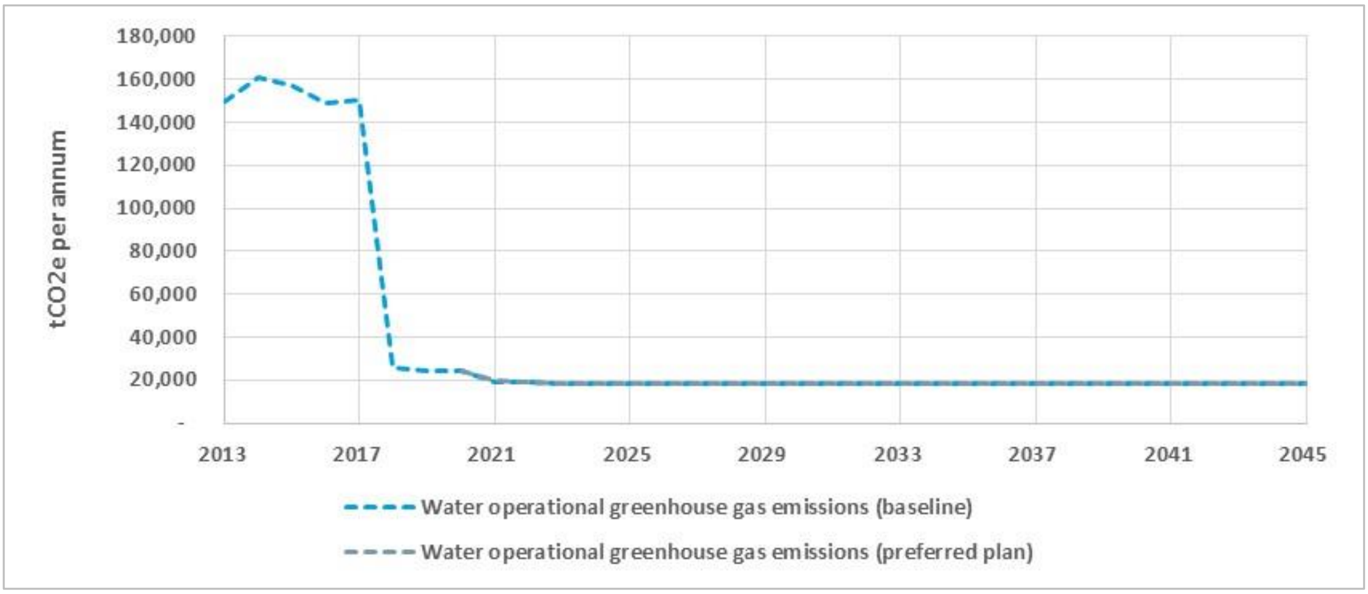

Figure 9 Greenhouse gas emissions as a result of our water service for our baseline activity and for our preferred plan

Table 21 Detailed data on greenhouse gas emissions

Option ID	Option name	Construction or implementation related carbon, including embedded carbon (total tonnes CO_2e)	Operation related carbon (tonnes CO_2e per year over the planning period)
Enhanced leakage reduction			
WR907d	LEA_THIRD PARTY_SRZ_31	828	0
WR907e	LEA_THIRD PARTY_SRZ_32	828	0
WR907f	LEA_THIRD PARTY_SRZ_33	828	0
WR907g	LEA_THIRD PARTY_SRZ_34	828	0
WR912	LEA_THIRD PARTY_SRZ_38	9	0
WR914	LEA_THIRD PARTY_SRZ_39	82	0
WR500a	LEA_SRZ REDUCTION_1	28	0
WR500b	LEA_SRZ REDUCTION_2	22	0
WR500c	LEA_SRZ REDUCTION_3	15	0
WR500d	LEA_SRZ REDUCTION_4	20	0
WR500e	LEA_SRZ REDUCTION_5	22	0
WR500f	LEA_SRZ REDUCTION_6	601	0
WR500g	LEA_SRZ REDUCTION_7	1,099	0
WR500h	LEA_SRZ REDUCTION_8	2,706	0
WR500i	LEA_SRZ REDUCTION_9	6,496	0
WR500j	LEA_SRZ REDUCTION_10	7,425	0
WR500k	LEA_SRZ REDUCTION_11	2,295	0
WR503	LEA_HH_SUPPLY PIPE	0	0
WR514	LEA_SRZ_TEMPORARY LOGGING	330	0
WR515	LEA_SRZ_DMA SPLITTING	60	0
WR517	LEA_SRZ_TILE SPLITTING	273	0
Resilience to other hazards			
N/A	Solution D	951,285	0

5.2.3 Drinking water quality

Our preferred plan needs to ensure that we continue to meet drinking water quality standards, minimise water quality risks and that the water we supply remains acceptable to customers; there should be no deterioration. This is in line with the latest Drinking Water Inspectorate guidance to water companies including its Long Term Planning guidance published in 2017. Our assessment of the impact of the preferred plan on drinking water quality is outlined in Section 7.5 of the *Final WRMP19* main report.

5.2.4 Environmental appraisal

As discussed in Section 1, at the start of the options appraisal process, options have already been screened to ensure they have no environmental impact, including a Strategic Environmental Assessment (SEA), Habitats Regulations Assessment (HRA) and Water Framework Directive (WFD) assessment. For the full SEA, HRA and WFD assessment of the impacts of our feasible options, and alternative and preferred plans, please refer to:

- Section 7.4.5 of our *Final WRMP19* main report
- *Strategic Environmental Assessment of the Revised Draft Water Resources Management Plan 2019: Environmental Report*
- *Strategic Environmental Assessment of the Final Water Resources Management Plan 2019: Post Adoption Statement*
- *Final Water Resources Management Plan 2019: Habitats Regulations Assessment*
- *Final Water Resources Management Plan 2019: Water Framework Directive Assessment*

Following the publication of the Environment Agency's position statement 'Managing the risk of spread of Invasive Non-Native Species through raw water transfers' (January 2017), we have also considered whether the options included in the preferred plan could pose a risk to the spread of invasive non-native species (INNS). The pathway created by the implementation of each of the options has been considered, rather than current occurrence of INNS. Where there is a transfer of raw water proposed, we have considered whether options will link isolated catchments or link catchments which are already connected. This initial assessment will inform whether mitigation measures need to be included in designing the new transfer, or, where already connected catchments are linked, an assessment of the increased risk that the option poses needs to be carried out. Further risk assessments and identification of mitigation measures will be carried out if the plan is adopted. Table 22 covers our approach in assessing the risks of spreading of INNS.

Table 22 INNS risk assessment of non-trading pathway

	Options required to address strategic choice	INNS risk assessment
Our preferred plan	**Leakage reduction** WR500a, WR500b, WR500c, WR500d, WR500e, WR500f, WR500g, WR500h, WR500i, WR500j, WR500k, WR501a, WR501b, WR501c, WR503, WR514, WR515, WR517, WR903b, WR903c, WR907d, WR907e, WR907f, WR907g, WR912 and WR914	Leakage reduction options will not need INNS risk assessments as there is no transfer of raw water.
	Manchester and Pennines Resilience Solution D "Rebuild all tunnel sections"	Solution D "Rebuild all tunnel sections" does not need an INNS risk assessment as there is no transfer of raw water.

We are also currently assessing the INNS risk relating to transfers in our existing supply system; this is outlined in our *Final WRMP19 Technical Report - Supply forecasting*.

6. Water trading adaptive pathway

As part of our options identification process, we discuss the potential for water trading with other water companies (as detailed in Section 8 of *Final WRMP19 Technical Report - Options identification*). This complemented collaborative work at a national level. Building on dialogue in the previous planning round, at the draft Water Resources Management Plan stage a potential trade to Thames Water from Lake Vyrnwy via a Severn-Thames transfer was explored (Section 3.4).

Given that a water trade has not been selected by other water companies in the core 25-year part of the planning horizon as part of their preferred plans (our preferred plan is outlined in Section 5), an updated version of the draft plan assessment has now been removed from our preferred plan and is now included in this section. This is because there is a strong possibility that water trading will take place in the future, either from Lake Vyrnwy, or from other sources and with other trading partners. As such we feel that our future planning should retain a strong focus on water trading, even though it does not specifically feature in our preferred plan. The adaptive pathway could form part of a future preferred plan in later planning reviews or cycles.

As discussed in Section 4.3.2, the analysis completed under the adaptive pathway is still based upon the earliest assumed date that a large-scale water Severn-Thames transfer would occur (in the 2030s), as in the *Draft WRMP19*, but in future the timing, size or utilisation of a trade could differ. For example, water could be traded to Severn Trent Water instead of, or as well as Thames Water, the trade could be smaller, or it could be at a different point in time. The flexibility of this concept is depicted in Figure 10 relative to our preferred plan (i.e. the non-trading pathway).

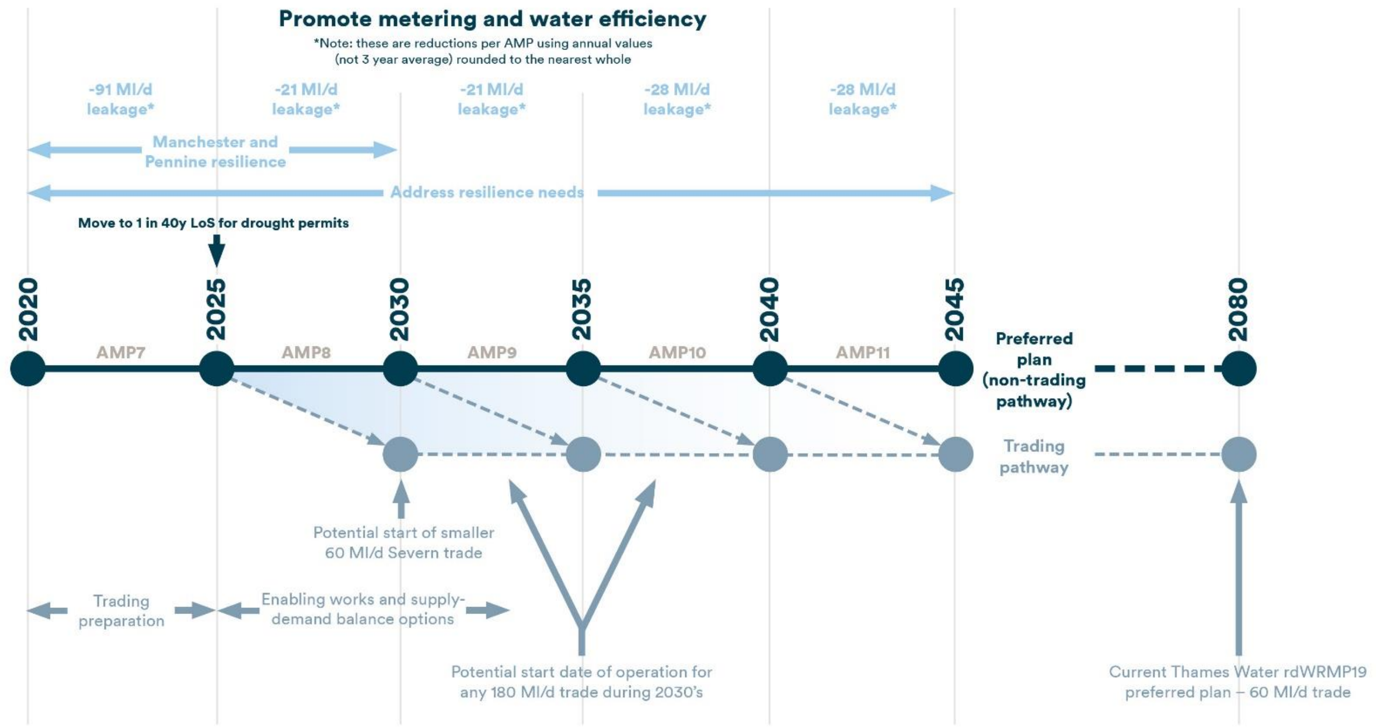

Figure 10 Water trading adaptive pathway

When considering national water trading, system performance (captured via the metrics in Section 4.4) was always determined by comparison against a baseline. In the 2030s model runs, performance was compared against the scenario in which 133 Ml/d of leakage reduction had taken place (see Appendix B for a list of all scenarios). When selecting the preferred portfolio, it was necessary to at least match the performance in this scenario, so that customers and the environment would not suffer any detriment through the strategic choices being considered (noting that customers would previously have paid for this investment to reduce demand, with the resultant benefits this provides). Our approach was driven by the clear customer and stakeholder concern that water trading would result in impacts to customers (e.g. levels of service, resilience) and the environment. Feedback indicated a requirement that these be protected. This guided our approach at the pre-consultation stage of the WRMP process. This was an important part of our extended methods options appraisal approach to developing a plan that would provide the necessary reassurance, whilst also preventing barriers to water trading that would otherwise occur (with the resulting loss of benefit to customers in other regions). Recognising that a surplus has an inherent value, for example, greater drought resilience, we do not feel that it is appropriate that customers lose this benefit (particularly noting that they would have paid for reduced leakage through their bills to get to that position).

In selecting the preferred portfolio the lowest cost set of options that would provide the desired performance were sought. However, some options that were not necessarily the cheapest were selected to serve specific purposes, such as protecting sensitive groundwater sources and reducing abstraction, i.e. they provided “best value” to meet our objectives.

A selection of some of the portfolios tested is shown below in Table 23. PF68 is the preferred portfolio. PF78 and PF79 have a lower cost, but do not meet our objective to protect customers and the environment. PF65 and PF80 while incurring higher cost, do not offer the same level of performance as PF68, i.e. they are a sub-optimal solution. PF82 incurred a significantly higher cost, yet did not give a significant increase in performance.

Table 23 Portfolio performance comparing to baseline with 133 Ml/d leakage reduction (trading adaptive pathway)

Portfolio and capacity of options	PF79 - 109 Ml/d	PF78 - 111 Ml/d	PF68 - 112 Ml/d	PF65 - 115 Ml/d	PF80 - 121 Ml/d	PF82 – 141 Ml/d
Scenario	2035_L133_T 300_Plus	2035_L133_T 300_Plus	2035_L133_T 300_Plus	2035_L133_T 300_Plus	2035_L133_T 300_Plus	2035_L133_T 300_Plus
Cost (NPV in £m with environmental and social costs)	135.7	140.5	140.6	147.3	157.0	206.6
Change in the likelihood of temporary use bans	+++	+++	+++	+++	+++	+++
Change in drought resilience	NSC	NSC	NSC	NSC	NSC	NSC
Change in river flows and implementation length of drought permits	++	++	++	+	+	+
Climate change resilience – change in the likelihood of temporary use bans	NSC	NSC	NSC	NSC	NSC	NSC
Climate change resilience – change in drought resilience	-	-	NSC	NSC	NSC	NSC
Change in abstraction from environmentally sensitive groundwater sources	++	++	++	++	++	++
Change in spill from reservoirs	++	++	++	++	++	++

The preferred portfolio for the trading pathway, based on the costs and metrics shown in Table 23, is PF68.

Table 24 Options trading pathway

	AMP7	AMP8	AMP9	AMP10	AMP11
Trading adaptive pathway (in addition to preferred plan)	Preparation for trading	Preparation for trading	**Trading enabling works will be brought online, as will several WRMP options, including:** **Water efficiency** WR610b education programme (1 Ml/d), WR620b goods and advice on metering (5 Ml/d) **Improved reservoir compensation release control** WR159 regional reservoirs (13 Ml/d), WR160 local reservoirs (9 Ml/d) **Develop existing groundwater sources** WR099b Worsthorne (4 Ml/d), WR101 Franklaw (30 Ml/d), WR102d Eccleston Hill (5 Ml/d), WR102e Bold Heath (9 Ml/d), WR105a Lymm (9 Ml/d), WR107b Randles Bridge (12 Ml/d), WR113 Tytherington (3 Ml/d) **Develop existing reservoir source** WR062b Worthington (12 Ml/d)		

As part of testing the draft plan we also completed a scenario of what a larger trade could look like, with more extensive use of Lake Vyrnwy (i.e. trading on a greater number of days). This is now excluded from Section 7 (scenario testing) as water trading does not form part of the preferred plan, but the results are still relevant to this pathway. The extended methods testing showed that with the adaptive pathway in place it would be possible to increase the use of Vyrnwy for trading without impacting customers or the environment. No new options would likely be required, but the level of utilisation of those selected would be higher. This helped to demonstrate a long-term best value plan following the aforementioned approach.

Were the trade to have a smaller capacity, for instance 90 Ml/d, from 2083 onwards a cheaper portfolio, with less capacity, would likely give performance that protected our customers and the environment. Whilst not tested quantitatively at this stage it is likely the portfolio would comprise the demand management and compensation flow reduction options, along with some of the more cost effective groundwater sources, selected for our adaptive pathway.

6.1 Using core methods

We've used a mock supply-demand balance need, based on the water available for use of the extended methods preferred portfolio, in EBSD modelling to allow a cost comparison and to generate information to submit in the Water Resources Planning Tables submitted alongside the *Final WRMP19* main report.

Method	Portfolio cost (NPV in £m with environmental and social costs)
Core	99.5
Extended	140.6

The core methods portfolio provides the same overall benefit in water available for use terms (i.e. the sum benefit of individual options) as extended methods portfolio, however it:

- Doesn't meet the extended methods objectives to protect customers and the environment;
- Has had no detailed assessment through SEA, HRA and WFD; and
- Does not properly account for the conjunctive water available for use under the trading configuration or option location, which is much more critical under trading and a reason for us selecting certain options.

6.2 Drinking water quality

Our preferred plan needs to ensure that we continue to meet drinking water quality standards, minimise water quality risks and that the water we supply remains acceptable to customers; there should be no deterioration. This is in line with the latest Drinking Water Inspectorate guidance to water companies including its Long Term Planning guidance published in 2017. Our assessment of the impact of the adaptive pathway on drinking water quality is outlined in Section 8.4 of the *Final WRMP19* main report.

6.3 Environmental appraisal

Section 5.2.4 covers the environmental appraisal of our preferred plan, however, we have also assessed the environmental impacts of water trading. Please refer to:

- Section 8.4 of our *Final WRMP19* main report
- *Strategic Environmental Assessment of the Revised Draft Water Resources Management Plan 2019: Environmental Report*
- *Strategic Environmental Assessment of the Final Water Resources Management Plan 2019: Post Adoption Statement*
- *Final Water Resources Management Plan 2019: Habitats Regulations Assessment*
- *Final Water Resources Management Plan 2019: Water Framework Directive Assessment*

Section 5.2.4 also covers our approach in assessing the risks of spreading invasive non-native species (INNS) for our preferred plan. Table 25 covers our approach in assessing the risks of spreading of INNS for our water trading adaptive pathway.

Table 25 INNS risk assessment of water trading adaptive pathway

Strategic choice	Options required to address strategic choice	INNS risk assessment
Water trading adaptive pathway	Water efficiency WR610b, WR620b and WR623b	Water efficiency options will not need INNS risk assessments as there is no transfer of raw water
	Improved reservoir compensation release control WR160 and WR159	Reservoir compensation release options will not need INNS risk assessments as there is no new transfer of raw water
	Develop existing groundwater sources WR099b, WR101, WR102d, WR102e, WR105a, WR107b, WR113	Development of groundwater source options will not need INNS risk assessments as there is no new transfer of raw water
	Trading enabling works	Trading enabling works will not need INNS risk assessments as water being transferred will have been treated
	Develop existing reservoir source WR062b	Water being transferred to treatment works rather than another waterbody. Risk assessment may be required, depending upon level of treatment before transfer.

The water trading adaptive pathway involves the transfer of raw water between the River Severn and the River Thames catchments. If this scheme is progressed it will require a more detailed INNS risk assessment. As the option is associated with national water trading there is sufficient time to undertake this work in the future and ensure that any risks are mitigated. The assessment of these elements of the scheme are covered in Thames Water's Water Resources Management Plan.

6.4 Enabling works under the water trading pathway

If water trading with a capacity of 180 Ml/d was taken forward, we would need to reconfigure the network to maintain a resilient supply of treated water to customers normally fed from Lake Vyrnwy. We refer to these changes as the 'enabling works'. They should not be confused with the trading portfolio of supply and demand options, which would ensure that all of our customers and the environment were protected under a trading arrangement, as described above. In essence the enabling works allow the trade to take place day-to-day, on a more local level, whereas the trading portfolio of options prevents deterioration in resilience across the Strategic Resource Zone.

Our engineers explored a number of different configurations for the enabling works. A total of eleven options were assessed, of which seven were able to facilitate the full 180 M/d trade[49]. The options fell into three categories:

1. Re-directing water abstracted from the nearby River Dee catchment (under existing licence conditions);

[49] Smaller trades were also considered

2. Re-directing water from other catchments in our supply area, including developing/upgrading a number of groundwater sources;
3. Transfers of water from higher in the Dee catchment.

The costs of the options were estimated, compared and refined in a series of steps as part of the selection process:

a) For all options, an Average Incremental Cost (AIC) was calculated, based on cost estimates of the major elements of the scheme;
b) For two shortlisted options, the AIC also including the minor elements of the scheme. Whole-life net present costs were calculated and two potential levels of utilisation were used; 50% and 15% (15% aligns with the anticipated frequency of the proposal, as explained in Section 8.2 of our *Final WRMP19* main report); and
c) For the selected option, AIC and NPV plus Average Incremental Social Cost (AISC), using estimated environmental and social costs. These were all calculated at 100% utilisation, and over a period of 80 years for consistency with the other options submitted in the WRMP tables. However, the values used in stage b) provided a more relevant trading-specific comparison of enabling works costs.

The two options shortlisted following step a) were selected on the following basis:

- As there were some concerns related to using water from the Dee catchment, one Dee option and one non-Dee option were taken forward. Following further assessment, these concerns were deemed to be mitigatable;
- Having the capability to facilitate the full 180 Ml/d trade; and
- Having the lowest AIC.

The refined costs for the two options selected in step b) are shown in the table below.

Table 26 Costs for the two shortlisted enabling works options

Option ID	Option type	NPV (40 year period)		AIC (p/m3)	
		15% utilisation	50% utilisation	15% utilisation	50% utilisation
A3	Category 2 (non-Dee sources; this specific option includes upgrades to existing groundwater sources)	£96m	£139m	140	46
B2	Category 1 (Dee catchment, see details below)	£71m	£91m	114	36

As shown in the table the lowest cost, and therefore selected option re-directs water abstracted from the River Dee catchment. In addition to our current abstraction licence it also utilises our existing water treatment works and network connections. It would, however, also involve constructing four new pumping stations to reverse the flow in one of our large diameter trunk mains. This element would provide just under 60 Ml/d of the alternative supply. Due to the associated increase in pressure we would need to upgrade or replace a total of 26km of pipeline. This water would also need to be retreated to mitigate the risk of discolouration linked with the pumping. A number of minor elements were included in the stage b) refined cost estimates, for example, equipment to allow flows to be reduced in some of the other large diameter trunk mains.

The final costs for option B2, calculated over 80 years and with 100% utilisation for consistency with the WRMP tables (stage c), are: AIC 40p/m^3; AISC 41p/m^3; and NPV £90.4m. As outlined in Section 8 of the *Final WRMP19* main report we have developed a water trading pathway as fully as possible, but it is just a proposal at this stage. We will continue working with potential trading partners to develop the proposals and include any updated information, including the design and selection of any enabling works, in the next WRMP.

No enabling works are required for raw water exports from Vyrnwy of up to 60 Ml/d. In addition, potable water exports to Seven Trent (which could be used to offset their abstraction from the River Severn) also do not require enabling works.

As discussed in Section 8 of our *Final WRMP19* main document the enabling works required would vary depending upon the size and nature of the trade. The enabling works selected were used as a robust representation of a potential requirement for this strategic assessment. If water trading were to become more certain further work would be undertaken to assess all aspects of the changes required to our supply system, including what enabling works would be undertaken and the potential impacts on the environment. Section 8.6 of our *Final WRMP19* main report describes further investigation and studies on water trading planned (between 2020-2025).

7. Supply-demand scenarios and stress testing

As discussed in Section 9 of our *Final WRMP19* main report, our preferred plan must be resilient to a wide range of uncertainties, such as the impacts of climate change, population growth and future customer demand for water. Whilst our extended methods process reflects uncertainties critical to the nature of our supply system and problem characterisation, discussed in Section 2.2, we have also created further supply-demand scenarios, in a similar manner to that in WRMP15, to "stress test" the preferred plan.

This approach enables a clear understanding of the 'tipping points' in EBSD, whereby different types of solutions (e.g. larger options) may be triggered and thus whether this is appropriate to consider in the context of longer term best value (e.g. could be tested in the extended methods framework). Primarily, as mentioned, we see the supply-demand scenarios as a method of stress testing the preferred plan. Table 27 shows the key uncertainties that could impact our plan and how we have created scenarios to stress test our plan.

Table 27 The key uncertainties that could impact our plan and how we have created scenarios to stress test our plan

Uncertainty or change	Creation of high impact[50] scenario or stress test	Resource zones impacted
Sustainability changes	As described in our *Final WRMP19 Technical Report - Supply forecasting*, this scenario works on the possibility of further sustainability changes being applied, due to the Habitats Directive and Water Framework Directive.	Strategic
Demand forecast[51]	In line with the uncertainties highlighted in Section 10 of our *Final WRMP19 Technical Report - Demand for water*, this scenario shows what would happen if all of our demand forecasting uncertainties materialised, known as the "high demand" or "upper" scenario.	Strategic, Carlisle and North Eden[52]
Climate change	As described in *Final WRMP19 Technical Report - Supply forecasting*, we have included the 50th percentile climate change impact in our baseline supply forecast. This scenario shows what would happen if climate change was worse than we anticipate, with the 95th percentile climate change impact being applied to the supply forecast.	Strategic (although, tested in extended methods) and Carlisle[53]
Leakage convergence	As discussed in Section 4.8 of our *Final WRMP19 Technical Report - Demand for water*, we have assessed several scenarios for leakage convergence. This scenario relates to leakage convergence scenario 1 and is the current view of the potential impacts of leakage convergence on our forecast of demand for water.	Strategic, Carlisle and North Eden[54]
Windermere licence review	In 2017, as part of developing our Final Drought Plan 2018, Defra requested that we review the Windermere abstraction licence, which authorises abstraction for public water supply from Calgarth. We have incorporated one of the scenarios from the review into our testing of the preferred plan. The scenario (referred to as "Scenario H" in the Windermere licence review study) involves increasing the hands off flow condition to 373 Ml/d all year round. This was selected following discussion with stakeholders, who selected it based on what was considered to be the best range of potential benefits and impacts on supply. It should not be assumed that the licence changes tested in the scenario would be chosen following the full review.	Strategic

To ensure there is no double counting of uncertainties, demand related target headroom has not been included in "high demand" type scenarios. This is similar to how climate change uncertainty is treated in extended methods, as discussed in Section 4.3.2, headroom percentile testing was completed as part of the baseline supply-demand balance assessment and is documented in our *Final WRMP19 Technical Report - Target headroom.*

[50] We have also created low impact scenarios to understand the variability in some of these uncertainties, e.g. climate change and our demand forecast. However, as the baseline position for all our resource zones is a surplus to 2044/45 (see Section 2.5), these low impact scenarios only lead to an increase in that surplus and have not been used to stress test our plan. However, they have informed our target headroom assessment, as documented in our *Final WRMP19 Technical Report - Target headroom*.

[51] Scenarios for demand management have also been created, e.g. a "no demand management" scenario. However, these were purely to understand the benefits of demand management and have not been used to stress test our plan.

[52] Demand in the Barepot Resource Zone is constrained by the operating agreement.

[53] We worked with Atkins to understand the vulnerability of each of our resources zone to climate change. This assessment showed that the Barepot and North Eden Resource Zones have a very low vulnerability to climate change and, following further assessment, a low risk of being impacted by it. Therefore, we have not included climate change scenarios for those resource zones.

[54] The Barepot Resource Zone constitutes a non-potable supply and will not be impacted by leakage convergence

Table 27 shows the scenarios used to test the plan, with supply-demand impacts and cost implications.

Table 28 Supply-demand scenarios used to test the plan, with supply-demand impacts and cost implications

Scenario	Uncertainty or change					Supply-demand balance impact in 2044/45 under the scenario (Ml/d)	Surplus or deficit in 2044/45 under the scenario (Ml/d)	Cost implication (NPV in £m with environmental and social costs)	Options selected
	Sustainability changes	Demand forecast	Climate change	Leakage convergence	Windermere				
Strategic Resource Zone									
Further sustainability changes	H	B	B	B	B	-8	177 (surplus)	N/A	N/A
High demand (inc. Northern Powerhouse)	B	H	B	B	B	-148	38 (surplus)	N/A	With our proposed leakage reductions, no new options are selected (compared to the draft plan, which selected supply options under this scenario), but shorter term demand increases may require an acceleration of our enhanced demand management programme
Climate change is worse than anticipated	B	B	H	B	B	Tested using Extended Methods			
Leakage convergence	B	B	B	H	B	-7	178 (surplus)	N/A	N/A
Windermere Licence Review	B	B	B	B	H	-25	160 (surplus)	63.8	Two groundwater options and two options to control the compensation from reservoirs (selected to prevent deterioration of system performance, e.g. resilience)
Barepot Resource Zone									
Further sustainability reductions	H	N/A	N/A	N/A	N/A	-4.1	1.7 (surplus)	N/A	N/A
Carlisle Resource Zone (Critical Period)									
High demand	N/A	H	B	B	N/A	-2.1	0.8 (surplus)	N/A	N/A
Climate change is worse than anticipated	N/A	B	H	B	N/A	-2.7	0.1 (surplus)	N/A	N/A

Scenario	Uncertainty or change					Supply-demand balance impact in 2044/45 under the scenario (Ml/d)	Surplus or deficit in 2044/45 under the scenario (Ml/d)	Cost implication (NPV in £m with environmental and social costs)	Options selected
	Sustainability changes	Demand forecast	Climate change	Leakage convergence	Windermere				
Leakage convergence	N/A	B	B	H	N/A	0.1	2.7 (surplus)	N/A	N/A
North Eden Resource Zone									
High demand	N/A	H	N/A	B	N/A	-0.2	3.4 (surplus)	N/A	N/A
Leakage convergence	N/A	B	N/A	H	N/A	0.0	3.5 (surplus)	N/A	N/A

As shown in Table 28, with our proposed leakage reductions, none of the scenarios/stress tests led to a supply-demand deficit. However, shorter term demand increases, assessed as a key demand forecast uncertainty[55], may require an acceleration of our enhanced demand management programme.

For the Windermere licence review scenario, as with any voluntary change or commitment, we have used a precautionary approach and have selected options to recover the deployable output lost as part of the change. This is as a proxy for ensuring customers do not suffer a deterioration in levels of service or system resilience, akin to the principle used for water trading. As part of a future WRMP, we would test customer views around any deterioration against any licence change proposals (and benefits identified).

[55] As highlighted in Section 10 of our *Final WRMP19 Technical Report - Demand for water*

Appendix A – AISC values and ranking in pence per cubic metre for our options

The charts in this section show the Average Incremental Social Cost (AISC) values and ranking for the feasible options in each of our resource zones. The calculation of these values is described in Section 2.2. For these charts, we have used a short name for each option, whereas our *Final WRMP19 Technical Report - Options identification* will refer to the full option name. The "WR" reference is consistent between the two reports. It's worth nothing that options with a negative AISC[56] have formed part of our proposed leakage reduction programme (see Section 3.1).

Strategic Resource Zone

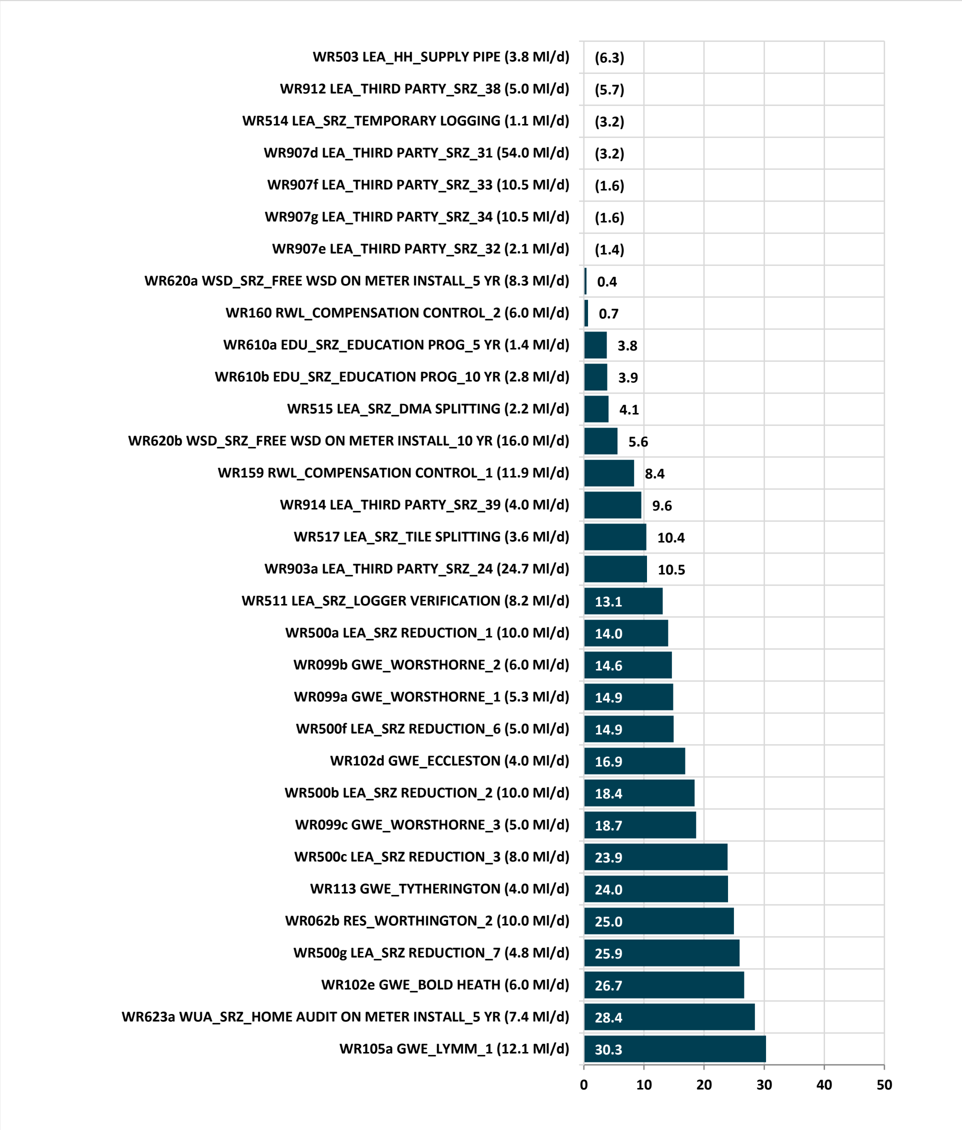

Figure 11 AISC values and ranking for options in the Strategic Resource Zone (1 of 3) (pence per cubic metre)

56 A negative AISC value indicates that an option is cost beneficial to implement irrespective of there being a supply-demand deficit to address

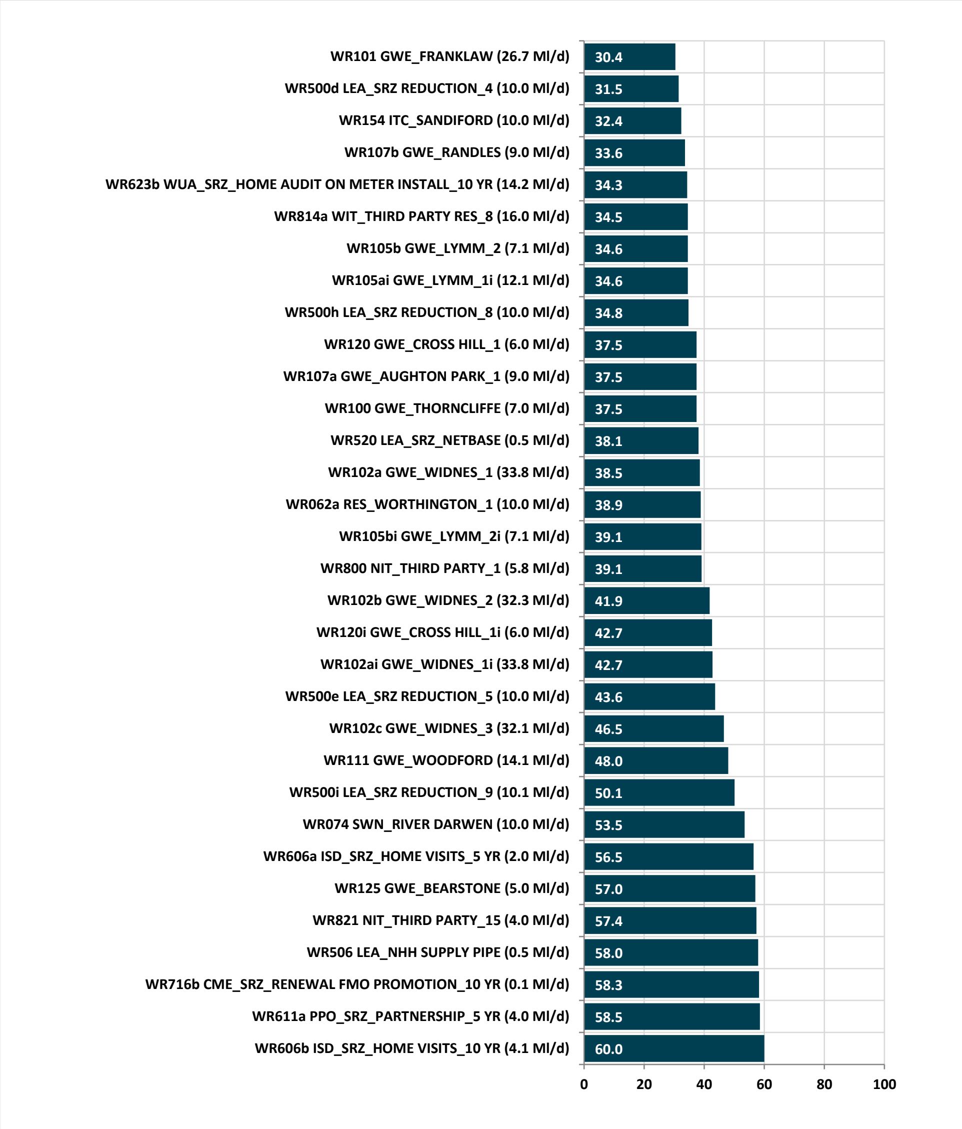

Figure 12 AISC values and ranking for options in the Strategic Resource Zone (2 of 3) (pence per cubic metre)

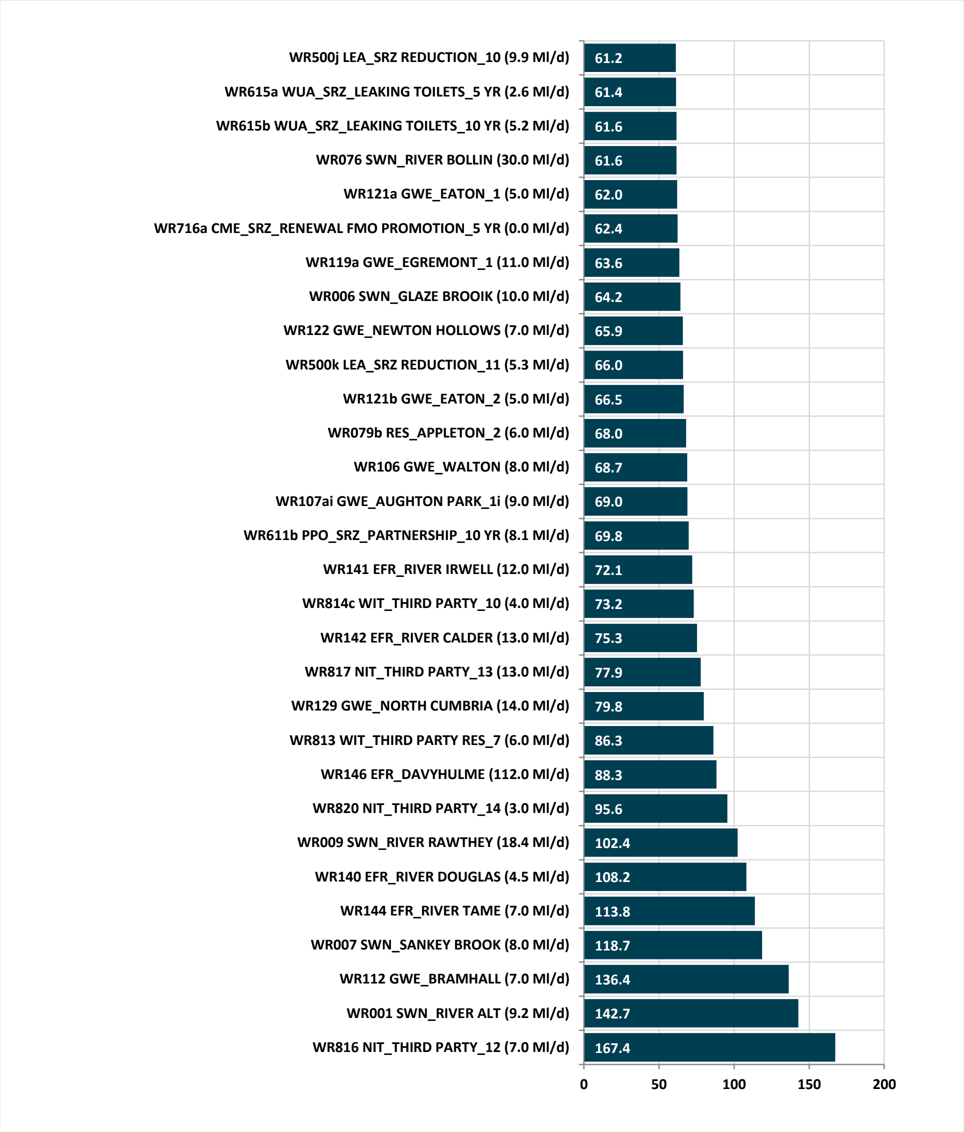

Figure 13 AISC values and ranking for options in the Strategic Resource Zone (3 of 3) (pence per cubic metre)

Final WRMP19 Technical Report - Options appraisal

Carlisle Resource Zone

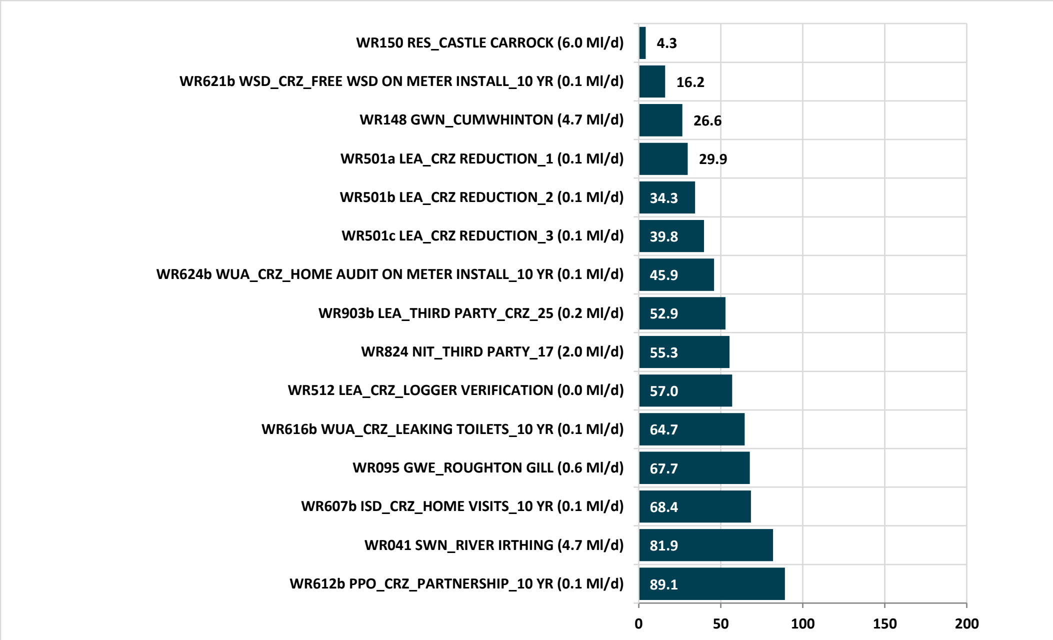

Figure 14 AISC values and ranking for options in the Carlisle Resource Zone (pence per cubic metre)

North Eden Resource Zone

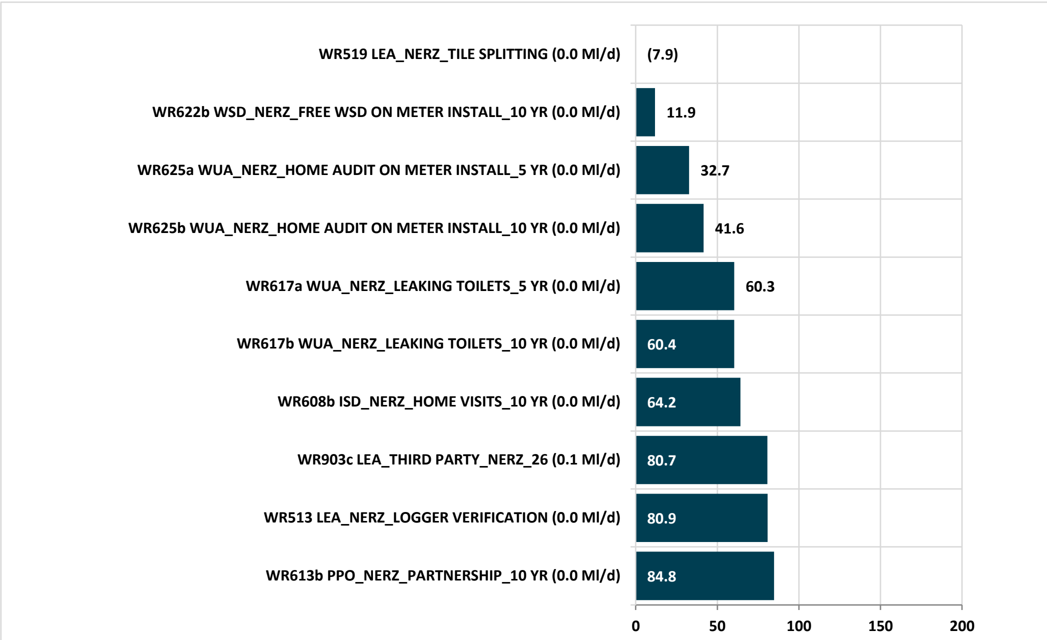

Figure 15 AISC values and ranking for options in the North Eden Resource Zone (pence per cubic metre)

Appendix B – Extended methods model run scenarios and nomenclature

Our supply-demand scenarios cover a wider range of uncertainties. These are illustrated in Section 6, where our extended methods process reflects those critical to the nature of our supply system and planning problem characterisation. Whilst the latter mainly focusses on supply-side uncertainty, as part of 'smart' evolution of our process we have been developing the plan, we have also now included demand within the framework. Table 29 shows the table of extended methods scenarios tested, with the relevant nomenclature used in the presentation of results.

Table 29 Table of extended methods scenarios tested

Run name	Run ID	Climate change setup	Demand for water setup	National water trading setup	Portfolio of options setup	Rationale
2035_Base	1	Circa. 50th percentile climate change impact at 2035 (referred to as "CCA")	Demand for water at 2034/35 plus target headroom (excluding the climate change component) plus outage and losses	N/A	N/A	Indicates expected system performance in 2035, with no leakage reduction and no options.
2035_L133	2	As **2035_Base**	As **2035_Base**, but includes 133 Ml/d of demand reduction through leakage	N/A	N/A	Indicates the change in system performance in 2035, with the proposed leakage reduction programme.
2035_L133_T300	3	As **2035_L133**	As **2035_L133**	Trade sized at 180 Ml/d, utilised in line with a 300 Ml/d abstraction from the River Severn	N/A	Indicates the change in system performance in 2035, if national water trading is added in without options.
2035_L133_T300_Plus	4	As **2035_L133_T300**	As **2035_L133_T300**	As **2035_L133_T300**	Includes options designed to return the customer and environment metrics back to the level indicated under **2035_L133**	Indicates the portfolio of options required to return the system performance to that with the proposed leakage reduction programme and no national water trading.
2035_L133_T300_CC resilient	5	As **2035_L133_T300_Plus**	As **2035_L133_T300_Plus**	As **2035_L133_T300_Plus**	As **2035_L133_T300_Plus**, but if the secondary climate change metrics show a negative impact the portfolio of options is changed to address this	Examine the extra options to make the system performance, under national water trading, resilient to climate change.
2035_L133_T300_Dem resilient	6	As **2035_L133_T300_Plus**	As **2035_L133_T300_Plus** with demand increased in case of demand forecast uncertainty	As **2035_L133_T300_Plus**	As **2035_L133_T300_Plus**, but if the metrics show a negative impact the portfolio of options is changed to address this	Sensitivity run to examine the impact of increased demand on our system.
2035_L133_T500_Plus	7	As **2035_L133_T300_Plus**	As **2035_L133_T300_Plus**	Trade sized at 180 Ml/d, utilised in line with a 500 Ml/d abstraction from the River Severn	As **2035_L133_T300_Plus**, but if the metrics show a negative impact the portfolio of options is changed to address this	Sensitivity run to examine impact of a higher utilisation of national water trading on our system.

Run name	Run ID	Climate change setup	Demand for water setup	National water trading setup	Portfolio of options setup	Rationale
2080_L220	8	Circa. 50th percentile climate change impact at 2080s	Demand for water in the 2080s plus target headroom minus climate change plus outage with 220 Ml/d leakage reduction	N/A	N/A	Indicates the expected system performance in the 2080s.
2080_L220_T300_CC resilient	9	As **2080_L220**	As **2080_L220**	Trade sized at 180 Ml/d, utilised in line with a 300 Ml/d abstraction from the River Severn	Includes options designed to return the customer and environment metrics back to the level indicated under **2035_L133**	Examine whether the portfolio of options assigned to support national water trading changes in the longer term.

Table 29 shows the table of extended methods scenarios tested for our Draft WRMP19, with the relevant nomenclature used in the presentation of results.

Table 30 Table of extended methods scenarios tested for our Draft WRMP19

Run name	Run ID	Climate change setup	Demand for water setup	National water trading setup	Portfolio of options setup	Rationale
2035_Base	1	Circa. 50th percentile climate change impact at 2035 (referred to as "CCA")	Demand for water at 2034/35 plus target headroom (excluding the climate change component) plus outage and losses	N/A	N/A	Indicates expected system performance in 2035, with no leakage reduction and no options.
2035_L60	2	As **2035_Base**	As **2035_Base**, but includes 60 Ml/d of demand reduction through leakage	N/A	N/A	Indicates the change in system performance in 2035, with the proposed leakage reduction programme.
2035_L60_T300	3	As **2035_L60**	As **2035_L60**	Trade sized at 180 Ml/d, utilised in line with a 300 Ml/d abstraction from the River Severn	N/A	Indicates the change in system performance in 2035, if national water trading is added in without options.
2035_L60_T300_Plus	4	As **2035_L60_T300**	As **2035_L60_T300**	As **2035_L60_T300**	Includes options designed to return the customer and environment metrics back to the level indicated under **2035_L60**	Indicates the portfolio of options required to return the system performance to that with the proposed leakage reduction programme and no national water trading.
2035_L60_T300_CC resilient	5	As **2035_L60_T300_Plus**	As **2035_L60_T300_Plus**	As **2035_L60_T300_Plus**	As **2035_L60_T300_Plus**, but if the secondary climate change metrics show a negative impact the portfolio of options is changed to address this	Examine the extra options to make the system performance, under national water trading, resilient to climate change.
2035_L60_T300_Dem resilient	6	As **2035_L60_T300_Plus**	As **2035_L60_T300_Plus** with demand increased in case of demand forecast uncertainty	As **2035_L60_T300_Plus**	As **2035_L60_T300_Plus**, but if the metrics show a negative impact the portfolio of options is changed to address this	Sensitivity run to examine the impact of increased demand on our system.

Run name	Run ID	Climate change setup	Demand for water setup	National water trading setup	Portfolio of options setup	Rationale
2035_L60_T500_Plus	7	As **2035_L60_T300_Plus**	As **2035_L60_T300_Plus**	Trade sized at 180 Ml/d, utilised in line with a 500 Ml/d abstraction from the River Severn	As **2035_L60_T300_Plus**, but if the metrics show a negative impact the portfolio of options is changed to address this	Sensitivity run to examine impact of a higher utilisation of national water trading on our system.
2080_L175	8	Circa. 50th percentile climate change impact at 2080s	Demand for water in the 2080s plus target headroom minus climate change plus outage with 175 Ml/d leakage reduction	N/A	N/A	Indicates the expected system performance in the 2080s.
2080_L175_T300_CC resilient	9	As **2080_L175**	As **2080_L175**	Trade sized at 180 Ml/d, utilised in line with a 300 Ml/d abstraction from the River Severn	Includes options designed to return the customer and environment metrics back to the level indicated under **2035_L60**	Examine whether the portfolio of options assigned to support national water trading changes in the longer term.

Appendix C – Key references and data sources

Table 31 List of key UK Water Industry Research (UKWIR) projects

Year	Manual/report name	Manual/report reference	Key components/elements that are informed/impacted
2002	The Economics of Balancing Supply and Demand	02/WR/27/4	Early framework for making supply-demand decisions and informs the core methods for options appraisal and selection
2012	Water Resources Planning Tools	12/WR/27/6	An extension to "The Economics of Balancing Supply and Demand" and informed the thinking for "WRMP19 Methods – Decision Making Methods"
2016	WRMP 2019 Methods – Decision Making Process: Guidance	16/WR/02/10	A key change for WRMP19, this project provided a framework for the consideration and application of advanced/enhanced decision making methods
2016	WRMP 2019 Methods – Risk Based Planning	16/WR/02/11	A key change for WRMP19, this project provided guidance and a methodology to aid in the understanding of risk through the WRMP19 planning process

Appendix D – Alternative plans consulted upon

Overview of alternative plans

The strategic choices, as documented in Section 3, were combined into four alternative plans for consultation, as shown in Table 32. In simple terms, Alternative Plan 4 was selected as our preferred plan because it contained all of the strategic choices we proposed to address customer and stakeholder views. Selecting Alternative Plan 3 would not have allowed us to continue to explore national water trading, thereby failing to meet a potential future national need, missing the opportunity to provide the associated bill saving to customers. Alternative Plan 2, whilst much cheaper than Alternative Plan 3, would not have allowed us to address pressing supply system resilience needs. Alternative Plan 2 had an additional estimated cost of £46.7m (net present value including environmental and social costs) compared to Alternative Plan 1, but helped to meet customer and regulatory aspirations on leakage reduction, as well providing environmental benefits and allowing us to improve our level of service for drought permits in 2025. Alternative Plan 1 had the lowest cost of all plans, but did not deliver any of the strategic choices.

Table 32 Our alternative plans for Draft WRMP19 consultation

Alternative plan	Pathway	What is the plan?	Why is this an alternative plan?
AP1	Non-trading	Continued demand management	This plan requires no extra investment, which helps with the affordability challenge. However, it does not offer the enhanced leakage reduction and improvement in the stated level of service for drought permits (and drought orders to augment supply), supported by customers, regulators and other stakeholders.
AP2	Non-trading	AP1 with 80 Ml/d leakage reduction by 2044/45 and an improvement in the stated level of service for drought permits and orders to augment supply	This plan requires investment in leakage reduction, but also enables us to improve in the stated level of service for drought permits and orders to augment supply.
AP3	Non-trading	AP2 with an increase in the resilience of our supply system	This plan requires investment in leakage reduction, but also further investment in resilience, specifically Manchester and Pennines Resilience, which as discussed in our *Final WRMP19 Technical Report - Water supply resilience*, has been highlighted as a risk in our supply system.
AP4	Trading	AP3 with further exploration of national water trading	This plan requires the investment in leakage reduction and resilience, as well as potential future investment to support national water trading.

Draft WRMP19 leakage programme

Table 33 below shows our Draft WRMP19 leakage programme proposal.

Table 33 Strategic Resource Zone leakage reduction options considered to deliver proposed WRMP19 leakage reduction (AMP7 covers 2020/21 to 2024/25, AMP8 covers 2025/26 to 2029/30, AMP9 covers 2030/31 to 2034/35, AMP10 covers 2035/36 to 2039/40 and AMP11 covers 2040/41 to 2044/45)

Focus	Option reference	Option short name	Leakage reduction (Ml/d)	AISC (pence per cubic metre)	Likely option start year	Rationale for programme choice
Reliability	**WR500a**	LEA_SRZ REDUCTION_1	10	8.5	2020/21	Selected for reliability to deliver AMP7 commitment
	WR500b	LEA_SRZ REDUCTION_2	10	10.5	2020/21	Selected for reliability to deliver AMP7 commitment
	WR500c	LEA_SRZ REDUCTION_3	8	12.9	2020/21	Selected for reliability to deliver AMP7 commitment
	WR907e	LEA_THIRD PARTY_SRZ_32	2	(1.4)	2020/21	AMP7 pilot to test reliability
Balanced	**WR500d**	LEA_SRZ REDUCTION_4	10	15.3	2025/26	Selected for reliability to deliver AMP8 commitment
	WR907f	LEA_THIRD PARTY_SRZ_33	10.5	(1.6)	2025/26	Will help deliver AMP8 commitment, if found to be reliable in AMP7 pilot
Innovation	**WR515**	LEA_SRZ_DMA SPLITTING	2	4.1	2030/31	High level of uncertainty
	WR503	LEA_HH_SUPPLY PIPE	4	(6.3)	2030/31	Potentially low reliability
	WR914	LEA_THIRD PARTY_SRZ_39	4	9.6	2030/31	High level of uncertainty
	WR907g	LEA_THIRD PARTY_SRZ_34	10.5	(1.6)	2035/36	Will help deliver AMP9 commitment, if found to be reliable in AMP7 pilot
	WR511	LEA_SRZ_LOGGER VERIFICATION	8	13.1	2040/41	High level of uncertainty
	WR514	LEA_SRZ_TEMPORARY LOGGING	1	(3.3)	2040/41	Small benefit, but combined with WR511 can help deliver AMP11 commitment

Draft WRMP19 portfolio performance, comparing to baseline with 60 Ml/d leakage reduction (trading pathway)

A selection of some of the portfolios tested for our *Draft WRMP19* is shown below in Table 34. PF23 is used for the preferred plan. PF15 has a lower cost, but did not meet our objective to protect customers and the environment. PF18 offered similar performance to PF23, but had a higher cost, i.e. it was a sub-optimal solution. PF19 and PF20 offered further benefits over PF23, however they had a higher cost, therefore we did not consider them to be a cost effective way to meet our objective.

Table 34 Portfolio performance comparing to baseline with 60 Ml/d leakage reduction (trading pathway)

Portfolio and capacity of options	PF15 - 104.7 Ml/d	PF23 - 110.7 Ml/d	PF18 - 123.7 Ml/d	PF19 - 133.7 Ml/d	PF20 - 159.7 Ml/d
Scenario	2035_L60_T300_Plus	2035_L60_T300_Plus	2035_L60_T300_Plus	2035_L60_T300_Plus	2035_L60_T300_Plus
Cost (NPV in £m with environmental and social costs)	159.1	169.5	184.1	202.4	254.9
Change in the likelihood of temporary use bans	+++	+++	+++	+++	+++
Change in drought resilience	NSC	NSC	NSC	NSC	NSC
Change in river flows and implementation length of drought permits	NSC	NSC	+	+	++
Climate change resilience – change in the likelihood of temporary use bans	-	NSC	NSC	NSC	NSC
Climate change resilience – change in drought resilience	NSC	NSC	NSC	+	+
Change in abstraction from environmentally sensitive groundwater sources	+	+	+	+	++
Change in spill from reservoirs	++	++	++	++	++

The *Draft WRMP19* preferred portfolio for water trading, based on the costs and metrics shown in Table 34, was PF23.