Appendix E – Decision making

Appendix E explains our investment modelling approach and how we use investment models as support tools to our decision making. The decision support tools used for our draft WRMP build on those developed for our previous water resource management plans and price reviews. We have used our Water Infrastructure Supply Demand Model (WiSDM) to derive a least whole life cost investment plan to meet our water infrastructure maintenance needs and supply demand balance over a 25 year planning horizon. This is discussed in section E1.

For this plan we have further enhanced our WiSDM model to create the Decision Making Upgrade (DMU) model, which explores the sensitivity of the investment plan under different future scenarios and considers the inherent uncertainty around delivery of solutions. This is covered in sections E2 and E3.

The outputs from these investment models have been used as part of our wider decision making framework which has considered the following aspects:

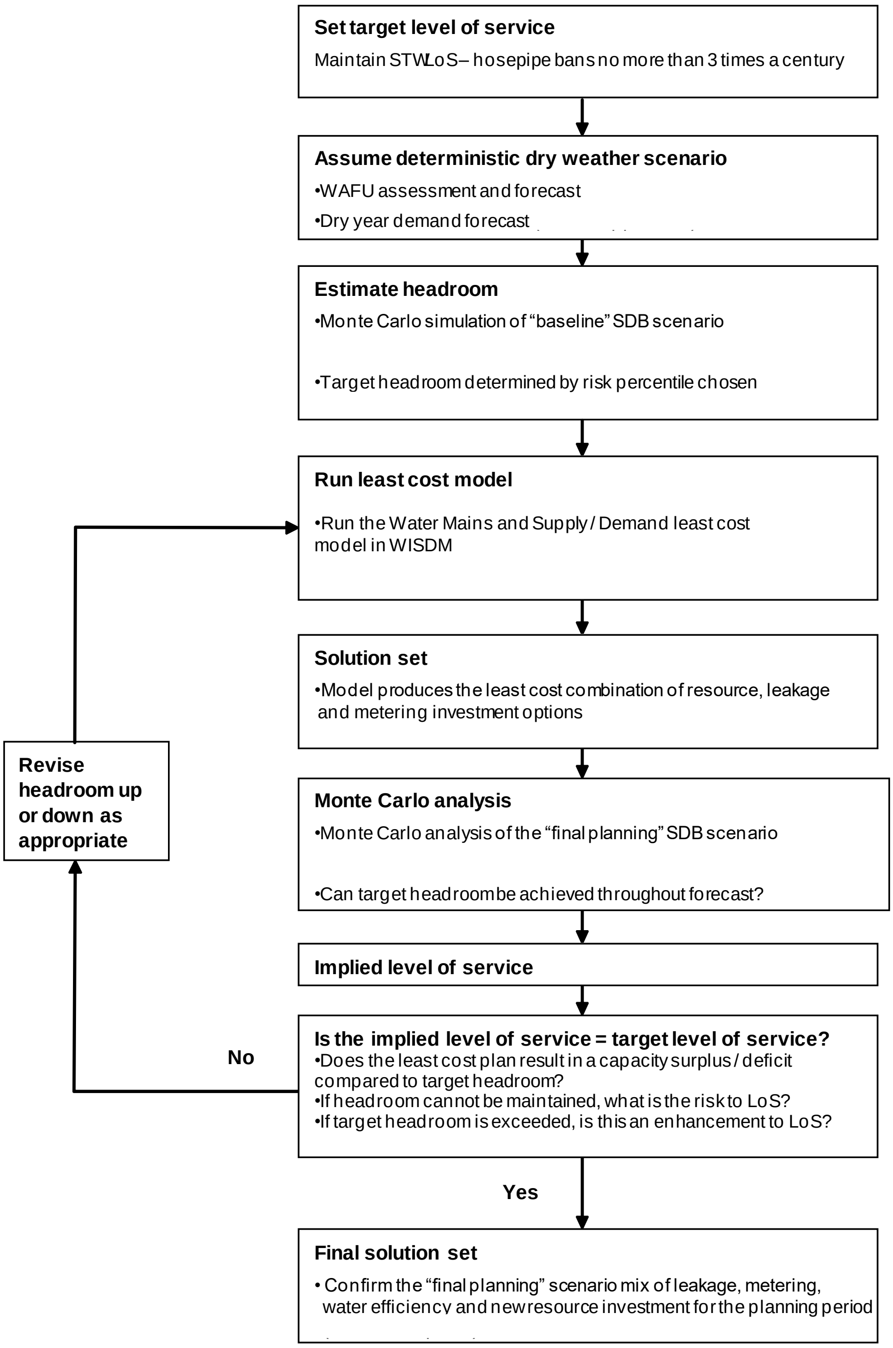
- Understanding regulators' expectations
- Understanding stakeholders' and customers' expectations
- Costs and benefits of options
- Supply / demand investment modelling
- Environmental impacts of our options
- Sensitivity testing of future scenarios
- Governance and assurance

The supply / demand recommendations in our WRMP have tried to balance all of these factors to produce a flexible, sustainable and affordable plan.

E1 The Least Cost Modelling Approach

The schemes that make up our strategy for water resources, leakage and water efficiency investment for ensuring security of supply, have been derived by applying the principles of the UKWIR/EA report Economics of Balancing Supply and Demand (EBSD). Our approach follows elements of the "intermediate" and "advanced" application of the EBSD methodology. The stages in the EBSD approach and how they relate to our WRMP are set out in Figure E1.1 below:

Figure E1.1: The stages in the "intermediate" EBSD approach



As explained in Appendix D, we have considered a wide range of potential options for balancing future supply and demand for water. We have considered the delivery risks and impacts of those options and have derived a final list of feasible options. Each of these feasible options has been taken forward for a more detailed assessment of long run financial, social and environmental costs and benefits. The costs and benefits associated with each of these schemes has then been used to determine the overall net least whole-life cost package of solutions to deliver the required security of supply over the long run to 2045 and beyond.

Our least cost investment plan has been derived using our Water Infrastructure Supply Demand Model (WiSDM). The model assesses the combined capital, maintenance and operating investment requirements associated with our infrastructure and non-infrastructure assets over the next 25 years. The model allows us to derive a truly holistic, least whole-life cost investment plan that meets our infrastructure maintenance and future supply / demand needs. As a result, the strategy set out in this WRMP is fully integrated with our wider capital maintenance and service delivery investment plans for PR19 and longer term.

The WiSDM model was originally built to inform the PR09 business plan and WRMP, and has been used as part of our business-as-usual investment planning activities throughout AMP5 and AMP6. The model was enhanced for PR14 and further so for PR19, including refreshing of the data sets and refinement of the supply scheme decision making.

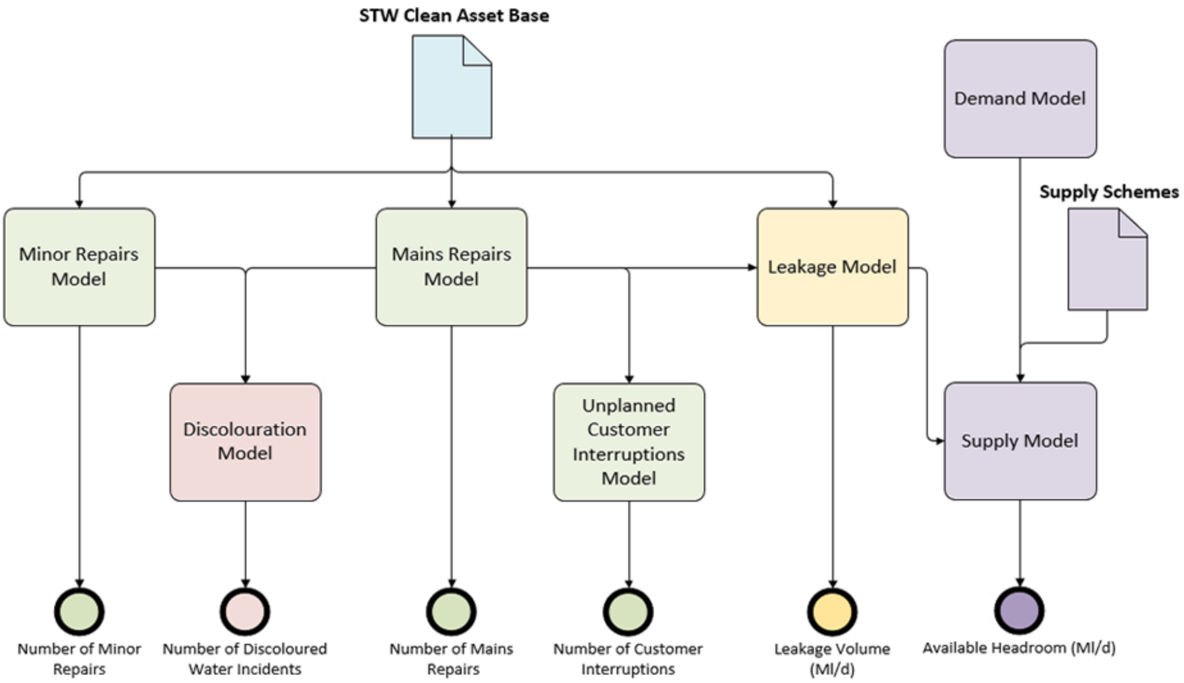
E1.1 Overview of the Water Infrastructure Supply Demand Model (WiSDM)

The WiSDM model is made up of six linked sub-models:

- Headroom
- Leakage
- Mains repair
- Interruptions
- Discolouration
- Ancillaries

The relationships between these sub-models are illustrated in Figure E1.2.

Figure E1.2: The components of the WiSDM model



Key	Category
	Asset Maintenance
	Water Quality
	Leakage
	Supply Demand Balance

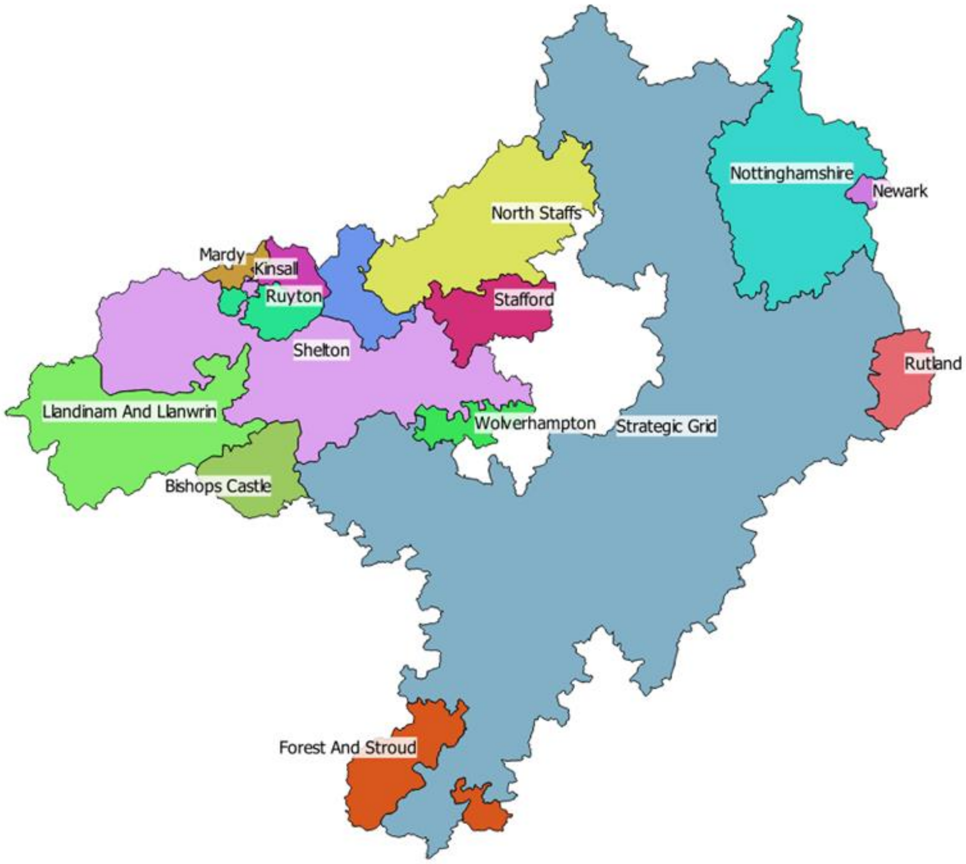
There are essentially three primary sub-models that predict the performance of our infrastructure asset base; mains repairs, minor repairs and leakage. The mains repairs model calls upon the asset attributes such as pipe material, diameter, year laid and soil setting to generate a mains deterioration profile. The repairs, by failure mode and diameter are then input to two secondary sub-models; unplanned customer interruptions and discolouration.

The minor repairs model is driven by the weighted average mains age of each WRZ, a component of which is also used by the discolouration model (valve repairs).

The leakage sub-model contains the base level of leakage by WRZ and applies a leakage deterioration component (NRR), which is driven by the weighted average age and material type of mains in the WRZ.
Future demand and headroom requirements are also taken into consideration in the model.
The integrated model calculates, for each water resource zone, the least cost mix of capital and operational interventions needed to prevent mains bursts and leakage increasing due to network deterioration, as well as to achieve the desired service targets for burst frequency, supply interruptions and leakage as well as maintaining target headroom throughout the planning horizon. Social and environmental costs of the chosen interventions are included in the least cost calculation resulting in a plan that is holistically least cost.

The model is split into 15 water resource zones as seen in Figure E1.3

Figure E1.3: STW WRZ split for WiSDM



The sections below provide a summary of the methodologies used in these sub-models. They define the assumptions made, the data used in the models, the inputs that have been taken from other studies and modelling, and the outputs that are available.

E1.2 The Headroom and Demand sub-model

The Headroom and Demand sub-model calculates the available headroom for each water resource zone based on water available for use, demand and leakage projections. The model's objective is to achieve and maintain target headroom by using demand management, reducing leakage or selecting new resource options to increase available headroom. Figure E1.4 below depicts the location of the sub model in the overall WiSDM hierarchy.

Figure E1.4 Headroom sub model

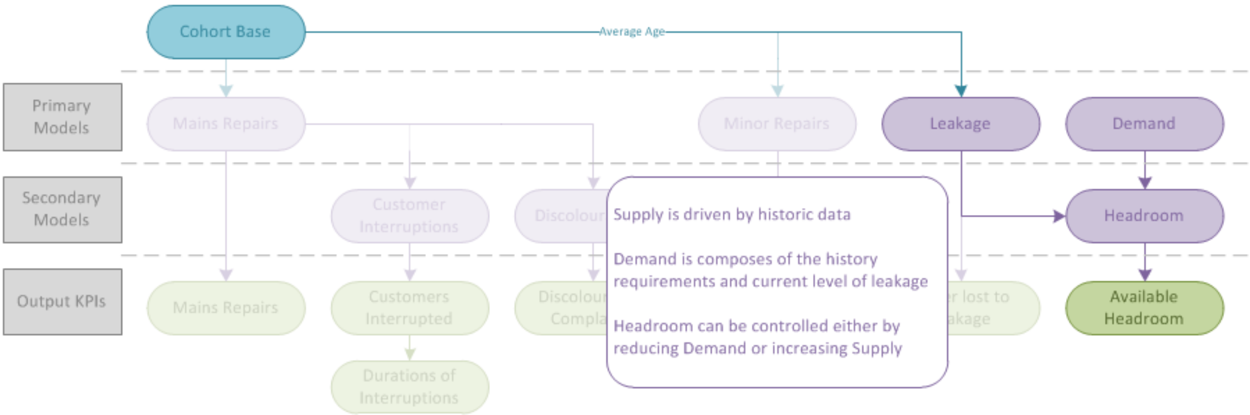
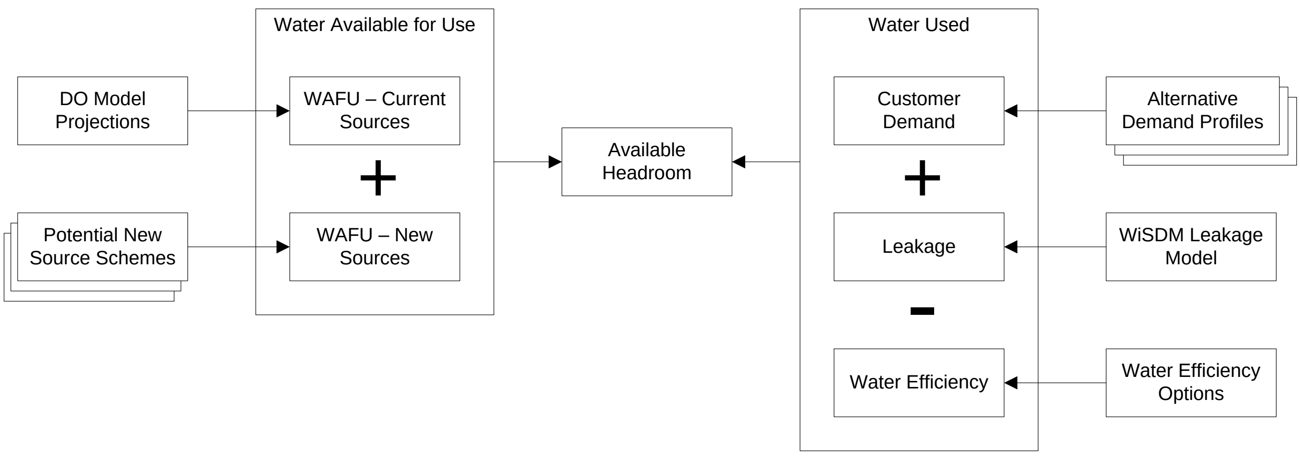


Figure E1.5 portrays the calculations within the model. Water available for use (WAFU) is made up of the predicted output from existing sources plus the contribution from any new resource schemes that the model has chosen.

The default baseline demand projection includes the benefits of our ongoing free meter policy and a continuation of our AMP6 water efficiency activities. The model then has options available to reduce demand further using compulsory metering, additional water efficiency measures or reducing leakage.

Leakage levels are calculated dynamically by the leakage sub-model and are a function of the underlying network deterioration and the chosen mains renewal and active leakage control interventions.

Figure E1.5 Calculation of available headroom in the WiSDM model



The WAFU and demand saving benefits of new sources/demand options are all input to the model at water resource zone level. Each option has associated with it the following data:

- Available daily output/benefit
- Construction costs
- Operation costs
- External costs (carbon and amenity / social)
- Dependencies with other options
- Inter-zonal effects if a scheme involves transferring water between zones

The key outputs from the Headroom and Demand sub-model are:

- Total water available for use
- Available headroom
- Distribution Input
- Household water delivered
- Numbers of meters installed
- Amount of active leakage control required
- Change in leakage level
- Level of enhanced water efficiency activity
- Resource options chosen
- Supply demand balance

Final distribution input is calculated through the arithmetic addition of water efficiency effects, metering benefits and the outputs from the leakage sub-model.

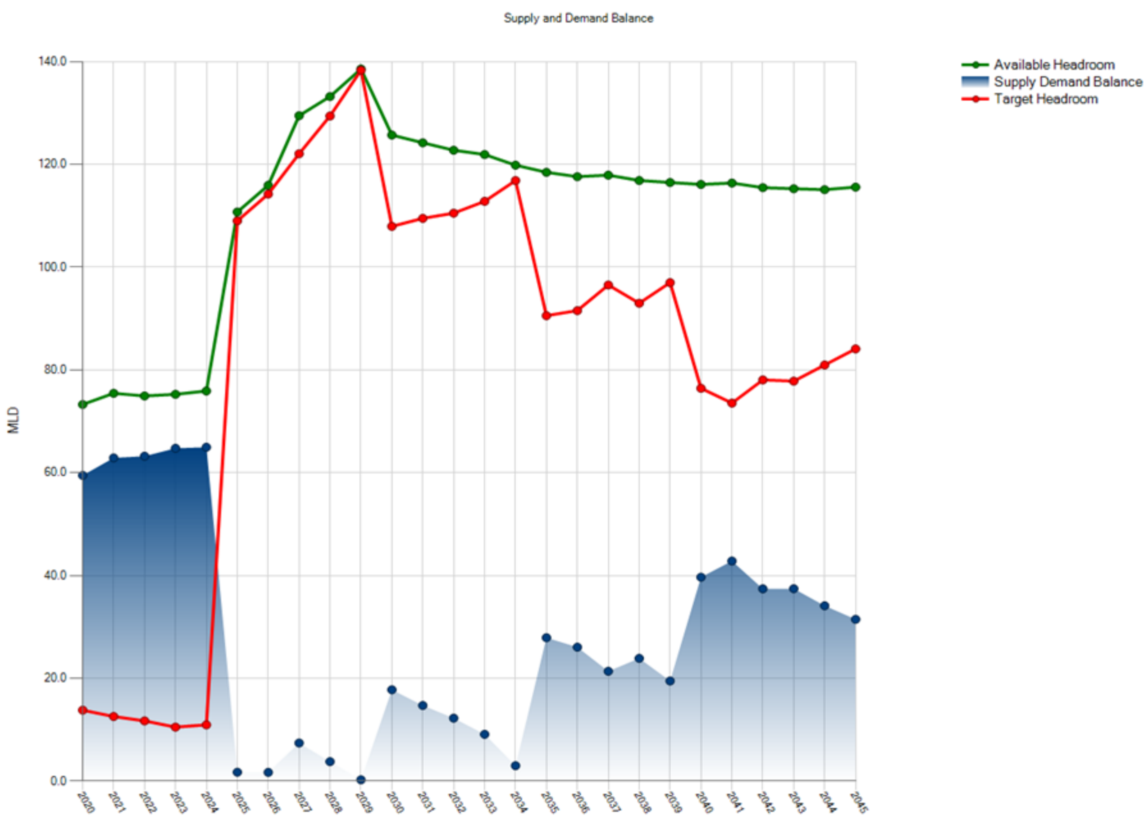
Total WAFU is calculated by adjusting WAFU with water provided from new supply schemes or water taken using transfer schemes.

Available headroom is modelled through the following equation:
Available Headroom (Ml/d) = Total WAFU – (Leakage + Demand)

Target Headroom is an input to WiSDM and is derived using a risk-based approach for assessing uncertainty, which is described in detail in appendix C.

The supply and demand balance is calculated by calculating the difference between the Available Headroom and the Target Headroom, as shown in Figure E1.6.

Figure E1.6 Supply and Demand Balance



E1.3 The Leakage sub-model

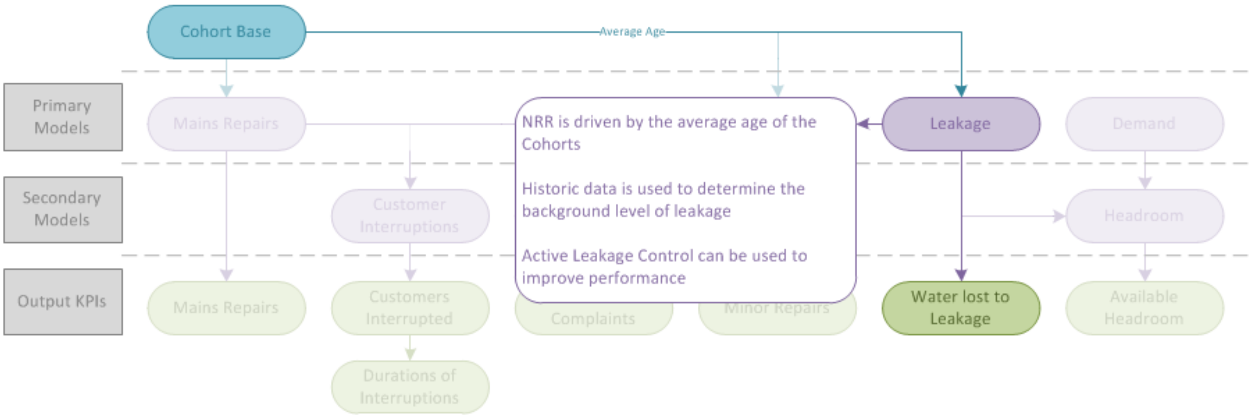
The purpose of the Leakage sub-model is to calculate the quantities of water lost through leakage based on the relationship between the mains age, mains type and soil setting for each WRZ. The model's objective is to calculate the level of leakage reduction required to achieve a least cost solution taking into account supply demand challenges and practical constraints.

We use the model to calculate the Economic Level of Leakage (ELL). The ELL is calculated in the optimisation by balancing the relative costs and benefits of combining different supply and demand-side interventions, alongside achievement of different service performance targets. The leakage target is an output not an input of the overall WiSDM model.

The leakage sub model allows us to explore the true economic level of leakage as well as the short and long run costs of achieving different leakage targets. On important constraint in the modelling assumptions is the policy decision that WRZ leakage can never rise over time. Therefore, decisions to reduce leakage to meet short term supply / demand needs have long term cost consequences as any reduction must be maintained over time using mains renewal and active leakage control. This modelling approach allows us to explore the 'true' economic level of leakage and understand long term mains renewal implications.

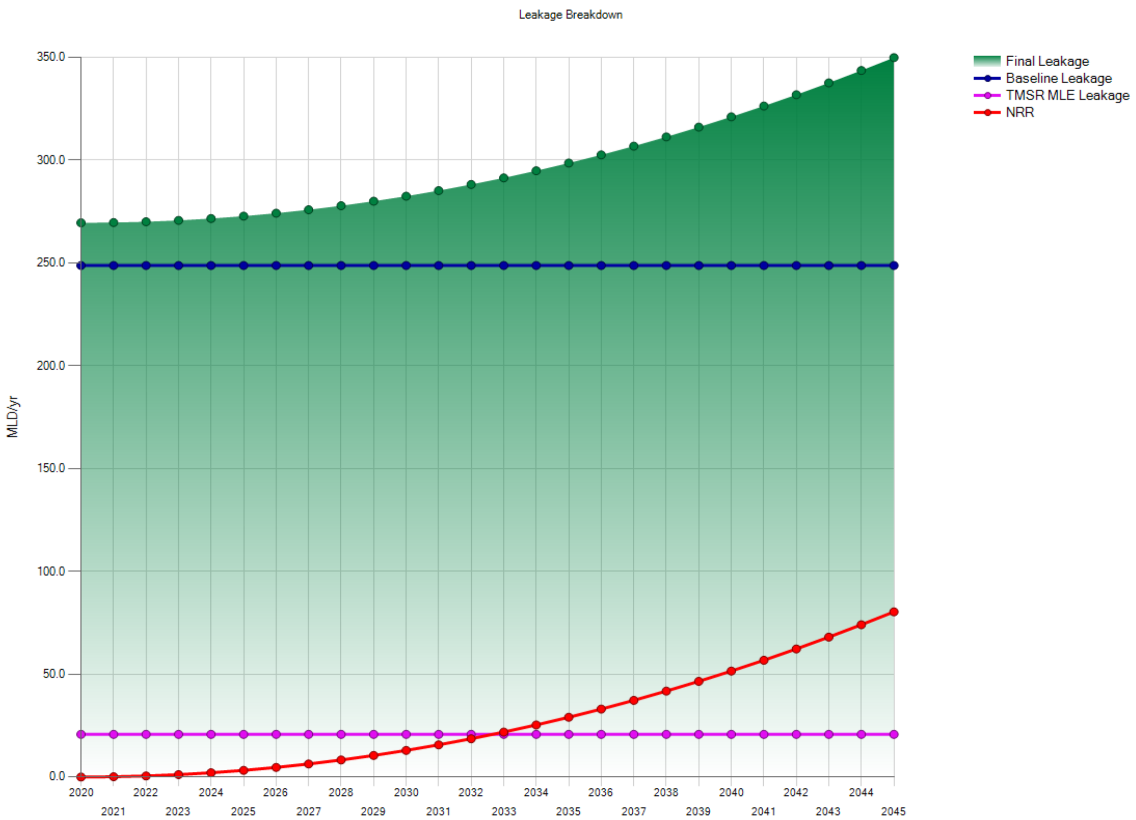
Figure E1.7 below depicts the location of the sub model in the overall WiSDM hierarchy.

Figure E1.7 Leakage sub model



The Leakage model sums the baseline level of distribution mains, trunk mains and service reservoir leakage, to which leakage natural rate of rise (NRR) is applied to calculate the amount of leakage control and mains renewal investment needed to prevent performance deteriorating over time. The effects of active leakage control and mains renewal needed to drive leakage down further for supply / demand purposes are then modelled to produce a 'Final Leakage' projection. Figure E1.8 illustrates how Final Leakage is broken down into the components of baseline leakage, trunk mains and service reservoir leakage and NRR.

Figure E1.8 Leakage Breakdown



The Active Leakage Control (ALC) intervention represents the effort and cost involved in finding and fixing leaks. It is configured in the model as a series of levels of reduction from current leakage to background levels (the minimum possible). The model can choose to do any number of leakage reduction levels in any one time step. The costs incurred for ALC include the cost of the effort to reduce leakage from one level to another and the cost of the additional effort needed to maintain leakage at the new lower level. The additional number of repairs, equipment needed, carbon and amenity costs associated with ALC are also calculated in the model and included in the calculation of the least cost solution.

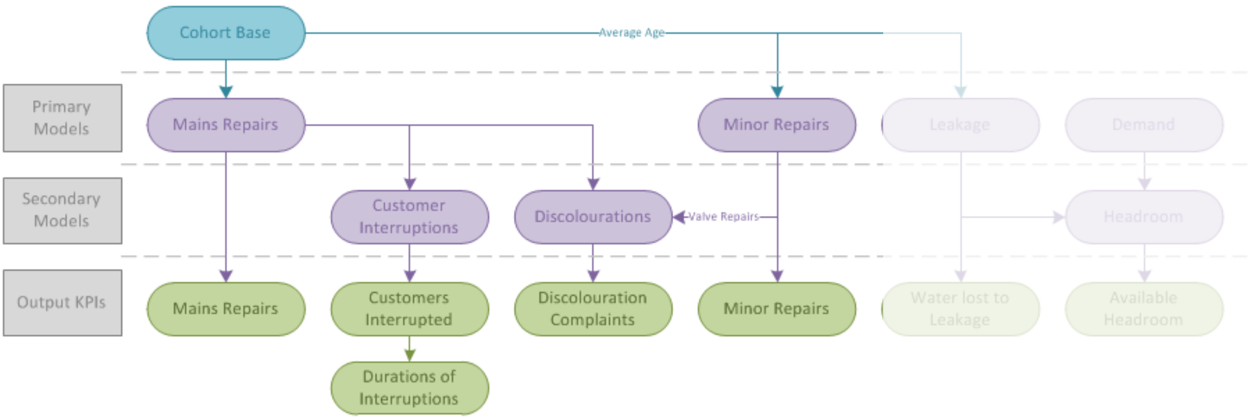
E1.4 The Mains Repair Sub-model

The purpose of the Mains Repair Sub-model is to predict the number of mains bursts based on relationships with the age and makeup of the network for each WRZ. The number of bursts and the mains material has a direct effect on the number of predicted unplanned customer supply interruptions. There is also a secondary effect on the number of predicted discolouration complaints as mains bursts are a trigger of discolouration events. The model's objective is to calculate the length of mains renewal required to maintain a stable number of mains bursts, prevent leakage from increasing and prevent an increase in the number of unplanned customer interruptions of greater than 12 hours and the number of unplanned customer interruption minutes greater than three hours.

Mains renewal, as well as acting on leakage breakout rate as described in the leakage sub-model section, is also used in the model to control the number of mains bursts and resulting unplanned interruptions through the moderation of the average age and material profile of the asset base. By holistically considering the benefit of mains renewal to leakage, mains bursts, unplanned interruptions, ancillary repairs and discolouration, we have ensured that the mains renewal investment profile is optimal. Decisions to reduce leakage as a means of meeting supply / demand targets have consequences for long term mains renewal rates needed to prevent leakage from increasing in future. This allows us to explore the true long run economic level of leakage through our WRMP analysis.

Figure E1.9 below depicts the location of the sub model in the overall WiSDM hierarchy.

Figure E1.9 Mains Repairs Sub Model

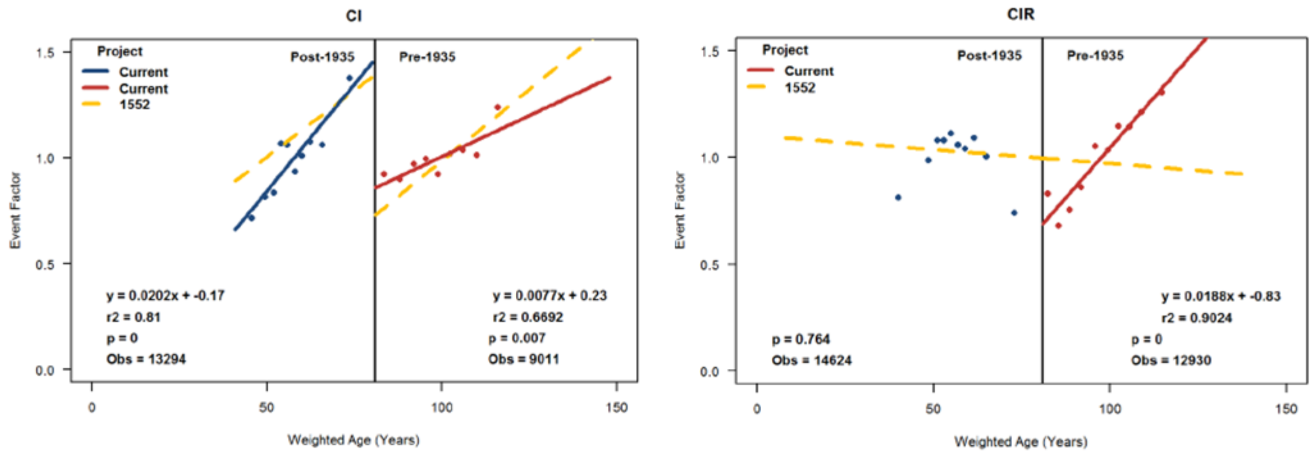


Company specific burst data is used to derive the deterioration relationships for each material, age, diameter and soil type. The two key relationships derived are detailed below with an example in Figure E1.10:

- A linear burst factor relationship for each material type by age. This is used to calculate the change in the number of bursts as the average age of the mains cohorts change.

- A multiplier relationship for each soil/diameter combination by material. This is used to modify the number of expected bursts taking into account ground conditions.

Figure E1.10 Burst factor relationships



The number of predicted unplanned customer interruptions resulting from mains burst is calculated in the Customer Interruptions sub-model. We have derived relationships between pipe diameter, material and location (urban or rural) and the number of customers interrupted and the duration of those interruptions. We constrain the model to keep the number of interruptions greater than 12 hours stable, this focuses mains renewal on larger diameter pipe in materials which tend to cause longer duration interruption events (asbestos cement and PVC). The benefit to discolouration complaints is a secondary effect as the number of complaints isn't constrained or targeted in the model.

This approach means that the short and long term decisions taken for supply / demand needs are fully integrated with the wider PR19 maintenance and service delivery investment plans.

E1.5 Model outputs

The WiSDM model produces output files by water resource zone for each simulation/ optimisation run as well as a series of graphical and tabular summaries. Figure E1.11 below illustrates the type of graphical output produced.

Figure E1.11a Illustrative graphical output from the WiSDM supply-demand balance modelling system

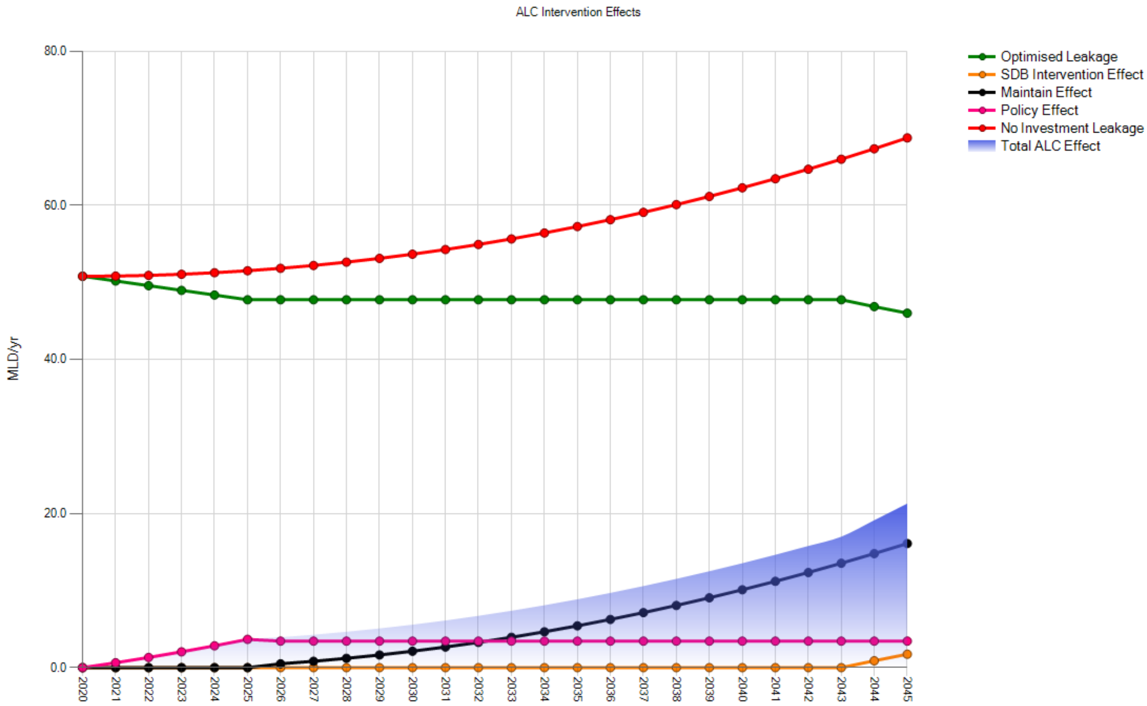
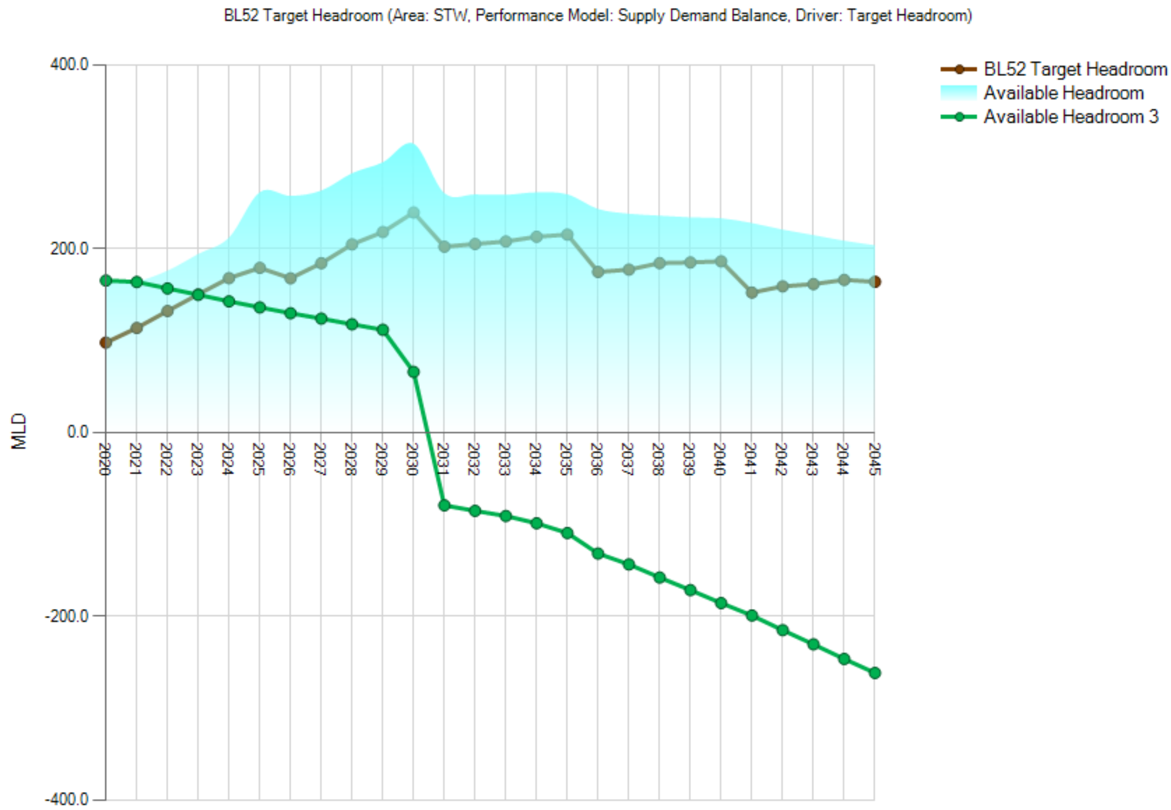


Figure E1.11b Illustrative graphical output from the WiSDM supply-demand balance modelling system



E1.6 Using WISDM outputs

The outputs of our WiSDM approach have allowed us to generate a number of potential long term investment programmes which represent different ways of securing our long term supply and demand objectives. We have also used the WiSDM model to test the costs and benefits of adopting different top-down policy decisions on issues such as leakage, metering and the pace at which we adapt to abstraction licence changes needed to achieve Water Framework Directive objectives. We have also examined water trading scenarios to explore how these options could impact on our long term investment needs, and what investment would be needed to achieve the strategic objectives of Water UK's Water Resources Long Term Planning Framework.
As a result, we have been able to generate a range of different feasible investment programmes and use these to test the cost implications of maintaining the supply / demand balance while achieving stakeholders' expectations.

We began running WiSDM investment scenarios in late 2016 when we first understood the potential scale of the abstraction licence changes needed to prevent future environmental deterioration and achieve Water Framework Directive objectives. As our understanding of the future supply and demand challenges improved through 2017, and with the releases of WINEP1 and WINEP2 by the Environment Agency, we ran further WiSDM modelling scenarios. The outputs of these evolving supply / demand investment scenarios allowed us to understand the expenditure implications for AMP7 and longer term, and allowed us to test alternative leakage and demand management scenarios.

The supply demand options including definitions of "Fropt" and "Enhanced Hwec and social housing" are included in Appendix D.

Table E1.1 summarises the list of WiSDM scenarios and potential investment programmes that we have generated through 2017 as our understanding of the supply / demand challenge and of our options evolved.

Table E1.1: WiSDM investment scenarios used to inform the dWRMP18

Scenario	Name	SDB	Leakage	Metering	Water Efficiency
0	Iteration 0 run	As per PR14	Min 3% leakage	Fropt	Base
1	Iteration 1 run	Dec 2016 from AMP 8	Min 3% leakage	Fropt	Base
2	As It 1 with new Water efficiency	Dec 2016 from AMP 8	Min 3% leakage	Fropt	Water efficiency v1.2xlsx
3	AMP 6 Mains profile capped	Time shifted Dec16 version (starting from 2017)	Min 3% leakage	Fropt	Water efficiency v1.2xlsx
4	Iteration 1 6%leakage + new headroom	Updated SDB - modified headroom	Min 6% leakage	PR19 updated Fropt	20 MeteringTemplate EDA v3.xlsx
5	Iteration 1 delayed RSA impact	March 17 delayed No deterioration	Min 6% leakage	Fropt	B20 MeteringTemplate EDA v3.xlsxase
6	RSA 2025	RSA from 2025, No WFD No Deterioration, Rank 50 Climate Change	Min 15% Leakage	Fropt	Enhanced (Hwec 6 + Social Housing 3)
7	SDB RSA 2025 WFD 2030	RSA from 2025, High WFD No Deterioration from 2030, Rank 50 Climate Change	Min 15% Leakage	Fropt	Enhanced (Hwec 6 + Social Housing 3)

8	S7 with enhanced metering profile	RSA from 2025, High WFD No Deterioration from 2030, Rank 50 Climate Change	Min 15% Leakage	Enhanced	Enhanced (Hwec 6 + Social Housing 3)
9	S7 w Water Trading	RSA from 2025, High WFD No Deterioration from 2030, Rank 50 Climate Change	Min 15% leakage	Fropt	Enhanced (Hwec 6 + Social Housing 3)
10	S6 re-run with stepped profile	RSA from 2025, zone specific High, Medium or Low WFD No Deterioration from 2030, Rank 50 Climate Change	Min 15% leakage	Fropt	Enhanced (Hwec 6 + Social Housing 3)
11	N/A	N/A	N/A	N/A	N/A
12	WINEP 2 with LCNR	WINEP 2 reductions, Rank 50 Climate Change	Leakage can never rise	Fropt	Enhanced (Hwec 6 + Social Housing 3)
13	N/A	N/A	N/A	N/A	N/A
14	WINEP 2 with LCNR and enhanced demand	WINEP 2 reductions, Rank 50 Climate Change	Leakage can never rise	Enhanced: 70k + Fropt	Enhanced (Hwec 6 + Social Housing 3)
15	WINEP 2 with LCNR and enhanced demand v2	WINEP 2 reductions w North Staffs correction, Rank 50 Climate Change	Leakage can never rise	Enhanced: 70k + Fropt	Enhanced (Hwec 6 + Social Housing 3)

Through this approach, we arrived at three feasible supply / demand investment programmes that could be used to achieve our long term supply / demand needs at very similar overall programme costs, but using different options: scenarios S12, S14 and S15. The overall net present value (NPV) difference between these three feasible programmes was approximately 3.5%, and was not considered material.

The headline difference between the supply and demand options we are recommending as part of the draft WRMP and the two alternative feasible programmes of similar NPV, relates to the potential impacts on a strategic water trade with Thames Water. The two alternative least cost programmes we derived included differing levels of leakage and metering ambition, but both included an option to develop a new water import to our region from United Utilities' Vyrnwy Reservoir via the River Severn. This transfer option also has the potential to feature in Thames Water's draft WRMP as part of a larger scale, national water trade. We have not included this water trade in our recommended preferred plan at this stage, but we will continue to explore this option with United Utilities as we prepare our final WRMP.

Instead, our recommended least cost programme includes a new scheme to purchase a third party asset and develop it into raw water storage to help meet our long term supply / demand needs. This is an innovative solution to develop strategic raw water storage in a way that minimises environmental impact. This scheme option features in our proposed investment plan for the period 2025-2030, which means that we have flexibility to continue exploring it alongside the water trading alternative during AMP7.

We then needed to go through some final steps to translate the outputs from S15 into the supply / demand inputs that have been used to populate tables WRMP6 Preferred and WRMP9 FP SDB. These steps are summarised below:

Appendix E: Decision Making

Step 1: Re-order S15 outputs based on environmental and engineering delivery risks
The outputs of WiSDM S15 represent the 25 year, least whole life cost package of demand, leakage and supply interventions needed to maintain the target supply / demand balance. Appendix D of the draft WRMP explains the option appraisal process that was used to derive the feasible list of options, and the costs and benefits assumed for each. The sequence of schemes generated in WiSDM S15 is optimised by the cost and benefit of each option, and that sequence generates the lowest net present value over the 25 year investment modelling horizon.

We have taken the outputs from this 25 year optimised package, and have then reviewed them based on planning, environmental and engineering criteria. In doing this we have also had regard to our overall WRMP strategic objectives:

We will use demand management measures to reduce the amount of water we need to put into supply by:

- reducing leakage on our network;
- influencing customers' water use behaviour using water efficiency activities and education; and
- increasing the coverage of water meters across our network to improve our understanding of water demand patterns.

While making the best use of our sustainable sources of supply by:

- reducing abstraction from those water sources that may be having a detrimental impact on the environment;
- making sure our future water abstractions do not pose a risk of environmental deterioration, as required by the Water Framework Directive;
- increasing the flexibility and resilience of our supply system;
- increasing or optimising deployable output from existing, sustainable sources where possible;
- using catchment restoration techniques to improve habitats and ecological resilience to low flows; and
- using catchment management measures to protect our sources of drinking water supply from pollution risks.

Using this approach we reordered the S15 sequence of scheme outputs so that we prioritised schemes that involve increasing / optimising output from existing water sources, and schemes with relatively low delivery uncertainty. Schemes that carried more delivery or environmental uncertainty were rescheduled to be later in the sequence so as to allow time for further feasibility studies.

Specifically for the North Staffordshire WRZ we overwrote the solution picked in WISDM S15. The WiSDM output chose solution Scheme UNK01 (New WTW on River Weaver) and solution Scheme BHS04 (new boreholes) based on the cost / benefit criteria given to the model. This demonstrated that the optimised supply / demand programme should include new scheme development of up to 27Ml/d. However, our review of the make-up of the WRZ and the reasons for zonal deployable output constraint demonstrated that these chosen solutions would not deliver water to the points of failure. Instead we overwrote these schemes with solutions Scheme UNK07 (Changes to Site L WTW treatment capacity) and Scheme GRD18 (New treatment process at Peckforton boreholes). These North Staffs solutions are more effective in delivering water to the location of model failure.

The reason we had to make this change to North Staffordshire is due to the definition of a Water Resource Zone. The baseline WRZ deployable output reflects the zonal demand that can be sustained at a common level of service base on the number of temporary use bans implemented throughout the zone. By making the RSA / WFD baseline licence changes in the Peckforton system, the effect is to either break the integrity of the WRZ and create a new smaller Peckforton / Coopers Green zone with a different level of service or leave the current zone with a large amount of “locked up DO”, because once the failure point it reached in one demand centre other sources stop supplying water to the rest of zone as well. WiSDM does not recognise this WRZ effect, and instead assumes that there is still one North Staffordshire zone with a much lower overall deployable output, and it seeks to replace this with the large new River Weaver scheme plus Swynerton. Our Aquator model review demonstrated that a much more effective solution is to prevent the loss of output from Peckforton boreholes and retain the integrity of the original WRZ, and therefore bring the zone back up by not just 6.5Ml/d but a total of 36M/d an increase of 29.5Ml/d.

This overall improvement to the wrz deployable output occurs because the scheme is targeted at the area of the zone which causes the failure. This means that not only does this demand centre receive more water (up to 6.5Ml/d), but also because the rest of the zone is now not being constrained by this failure, therefore other supplies are no longer “locked up” and they can continue to other parts of the WRZ and bring the overall zonal DO back up to around that of baseline an increase of 29.5Ml/d across the rest of the zone.

Step 2: Test that the reordered schemes still satisfy the supply / demand problem
We reconfigured the WiSDM S15 results to reflect the re-sequenced scheme options from Step1. We then tested whether this reordering combined with the chosen metering, demand management and optimised leakage reduction profile still satisfied the supply / demand problem.

This revealed that some reprofiling of the optimised leakage reductions was needed to ensure no small target headroom shortfalls within AMP periods. The end of AMP7 and end of AMP8 leakage reduction, metering and demand management volumes remained the same as output by S15. The list of supply enhancement schemes also remained the same as output in S15, but with the rescheduling described in Step 1. We renamed this output WISDM S17.

We tested whether rescheduling the optimised package of supply solutions caused any material change to the calculated NPV of the overall optimised S15 investment programme.

Step 3: Import the rescheduled WISDM S17 outputs into WRMP table 6.
We copied the leakage reduction, demand management, metering savings and supply enhancement benefits and schedule from the WiSDM S17 outputs into WRMP table 6 Preferred list of water management options.

E2 Sensitivity testing the least cost plan

As discussed in section E1, previous versions of the WiSDM decision support tool have been used to inform price reviews and Water Resource management plans since 2009. For PR14 and WRMP 14, extensive sensitivity testing was carried out on the WiSDM model to better understand the assumptions behind it. Our previous approach to sensitivity testing the WiSDM outputs gave the following benefits:

- helping determine the robustness of the plan - a plan can be considered robust if changes to input parameters do not significantly alter the proposed solution;
- identifying the critical input parameters (those that have large effects on the plan) – this may trigger a review of the original parameter specification or how these parameters are treated within the model;
- improving communication – having a range of outputs and increased understanding of the system removes the 'black box' nature of optimisation;
- identifying modelling errors – sensitivity analysis sometimes throws up strange results that cause the analyst to reconsider modelling assumptions.

For this dWRMP18, we made enhancements to our WiSDM model to go beyond the traditional approach to sensitivity analysis. These enhancements allow the investment optimisation to more explicitly account for uncertainty parameters around the supply and demand options, as well as considering a range of alternative future scenarios. This Decision Making Upgrade (DMU) to our WiSDM investment model has given us the ability to compute large amounts of supply / demand and options data and present it in a repeatable format. This has informed our internal decision making, and our ability to test the cost implications of meeting different supply / demand challenges and what our whole life cost investment plan might look like under a range of alternative futures.

We have used the DMU to model a large number of different supply / demand scenarios to examine how sensitive our investment decisions are to any uncertainty around costs and benefits of options as well as different supply / demand planning assumptions. These scenarios represent different possible 'alternative futures' which have allowed us to test the sensitivity of our plan to different possible combinations of events. These alternative futures were generated by varying those supply / demand factors that have the greatest uncertainty, including the scale and pace of future sustainability reductions, impacts of Water Framework Directive, climate change and future demand for water. Each scenario used a bespoke "water available for use" profile reflecting the deployable output impacts of the component being investigated and a "high", "mid" or "low" demand profile.

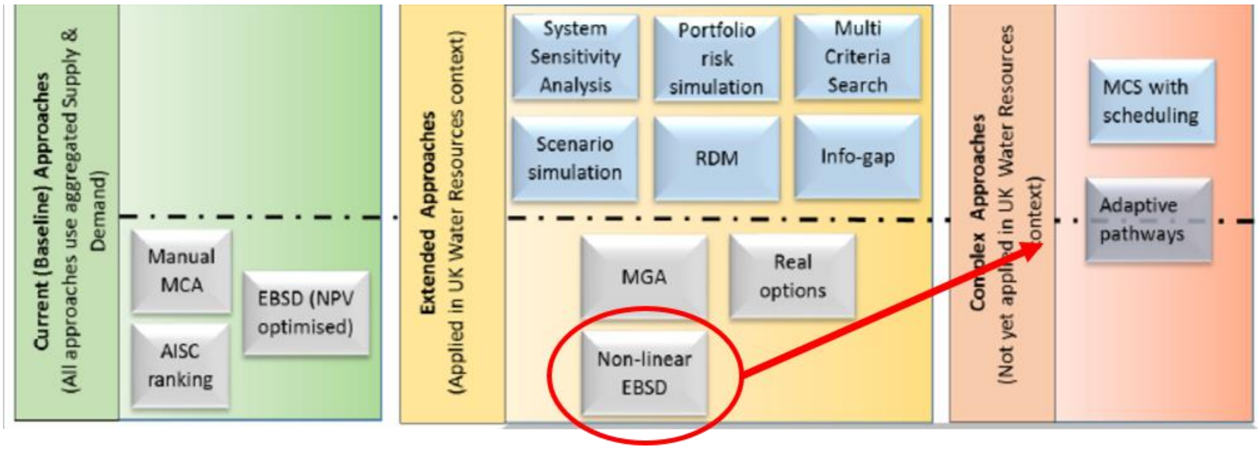
In August 2017 we ran 6000 DMU supply/demand investment optimisations, covering 60 different possible future scenarios. Scenarios covered the range of high / medium / low demand, WFD and climate change scenarios, along with multiple combinations of these different possible futures. We used frequency analysis to examine how different scheme options are chosen in the 6000 different optimisations, how certain we can be that different options will deliver the expected benefits, and to investigate how sensitive our investment programme is to the different supply / demand planning assumptions.

The outputs of this analysis has informed the supply / demand scenarios we used in WiSDM scenarios S12 to S15, and has defined the pace and magnitude of our chosen leakage and demand management targets. We also used the analysis to test how robust our supply / demand choices are in a range of possible futures.

E2.1 The Decision Making Upgrade (DMU)

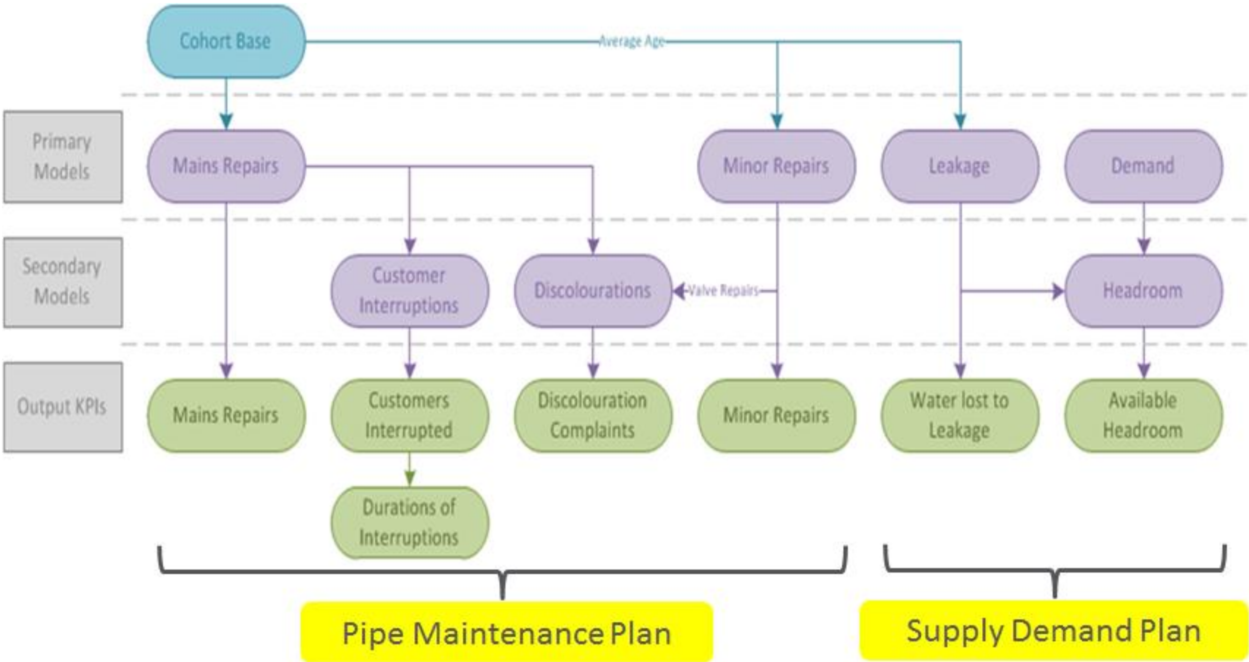
Early on in our preparation for the draft WRMP, we applied the UKWIR problem characterisation approach, which demonstrated that our emerging supply / demand challenges presented a large and complex problem to solve and so would require enhanced investment modelling methods. As seen in Figure E2.1, our WiSDM model already sat within the "Extended Approaches" category. The DMU enhancement was designed to move our investment modelling capability further into the "Complex Approaches" category.

Figure E2.1: The UKWIR decision making methods and tools. **Source: UKWIR 2016, WRMP 19 Decision Making Guidance, Report Ref. No. 16/WR/02/10**



The DMU builds on the WiSDM approach to investment optimisation modelling. Figure E2.2 shows how the components of WiSDM create two linked outputs – the pipe maintenance investment plan and the supply / demand investment plan.

Figure E2.2: The components and the outputs of WiSDM



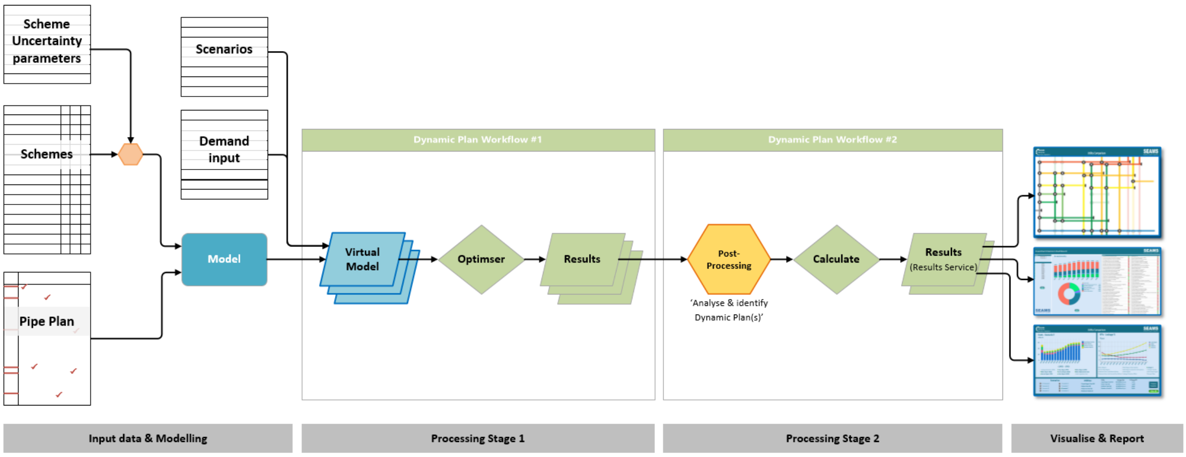
Appendix E: Decision Making

The overview of the DMU process is shown in figure E2.3. There are 4 main stages:

- Input data & Modelling
- Processing Stage 1
- Processing Stage 2
- Visualisations and Report

This section of Appendix E will discuss the stages of the DMU process, and then show some of the visualisations and analysis that have been used to inform the WRMP.

Figure E2.3: Overview of the DMU process

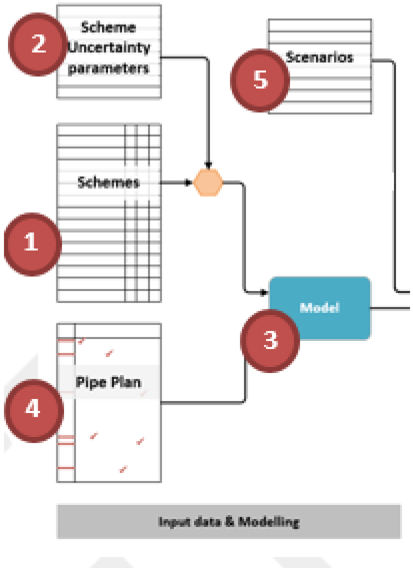


E2.1.1 DMU – Stage 1: Inputs data and modelling

The first stage of the process has 6 steps, which are shown in figure E2.4:

1. Define supply and demand schemes (same as in WiSDM)
2. Uncertainty Parameters around supply and demand schemes for 3 parameters:
    a. Time to benefit
    b. Additional WAFU or Demand reduction
    c. Totex Costs
3. Run WiSDM model using 'best central estimates' of data
4. A fixed pipe maintenance plan from WiSDM
5. Define alternative supply / demand scenarios – which cover a span of different potential supply / demand futures which reflect different planning assumptions including:
    a. Climate change
    b. Headroom uncertainty
    c. Demand projections
    d. Water Framework Directive (WFD) no deterioration
    e. Extreme Drought

Figure E2.4: Overview of stage 1 of the DMU process



To generate the pipe plan used in step 4, WiSDM is run under a best central estimate scenario. This generates a long term mains renewal and pipe plan that will prevent long term leakage increasing due to mains deterioration. The pipe maintenance plan output is then fixed and used as an input to the DMU process.

In WiSDM, the cost / benefit variables for the different intervention options (time to benefit, cost, benefits) are all fixed, but for the DMU uncertainty ranges are considered. The values for the uncertainty around these cost / benefit variables are statistically distributed using a Normal Distribution. The intervention options include the new supply scheme options, as described in Appendix D as well as the potential demand interventions including Active Leakage Control (ALC) and enhanced Water Efficiency programmes.

The DMU model generates multiple optimisations of a supply / demand scenario, taking account of the uncertainties around the costs and benefits of the potential intervention options. To take account of these uncertainty parameters, sampling analysis must be undertaken. In the DMU we use Latin Hypercube sampling, as opposed to the traditional Monte Carlo analysis. This is discussed in detail in section E2.1.2. One hundred optimisations are taken per scenario, each taking different samples from the options' cost / benefit uncertainty ranges using the Latin Hypercube approach. Each of these 100 optimisations is the equivalent to a single run of the supply / demand components of WiSDM.

This process is repeated for each of the 60 different supply / demand scenarios considered, resulting in 6,000 optimisations per DMU modelling run. A supply / demand scenario, or "Alternative Future", has been defined by different combinations of the various planning assumptions that affect WAFU, demand and headroom. The scenarios used in the DMU are discussed in section E3.

E2.1.2 DMU – Latin Hypercube sampling

Traditionally, for example in the WiSDM sensitivity analysis at PR14, Monte Carlo Analysis is used as a sampling technique. In the DMU, 1,000 Monte Carlo samples for 60 scenarios would result in 60,000 optimisations which is computationally intensive as well as requiring large amounts of data storage and creating a tremendous amount of data to analyse.

Latin Hypercube sampling is a variant of Monte-Carlo analysis in which input distributions are sampled in a more structured way. Each input distribution is split into *N* quantiles (i.e. equal percentile ranges which, therefore, each contain the same probability), where *N* is the number of simulations to be calculated in the study. The splitting of the distribution is completed using the inverse of the cumulative distribution function of the input distribution, the quantile function.

When sampling an input distribution, instead of selecting a value fully at random as with the more traditional variations of Monte-Carlo, we first randomly select a percentile range. Specifically, a percentile range that has not yet been used before and randomly selecting a value from within that range.

As a result of the more structured Latin Hypercube approach to sampling, two significant benefits are gained:

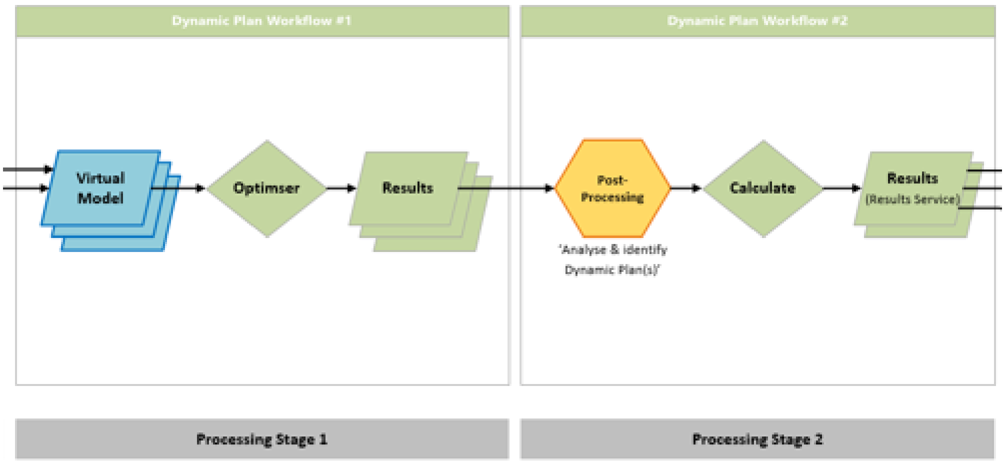
1. The aggregate result is not prone to skewness
2. Convergence occurs in a smaller number of iterations.

As such, a better result can be obtained with a smaller sample size. For the DMU, we use a sample size of 100.

E2.1.3 DMU – Stage 2 and 3: The Processing Stages

In processing stage 1, "Virtual models" are created to optimise least cost plans for the chosen scenarios under the sampling conditions defined. This results in 6,000 optimisations, each of which generate their own results file. This process is illustrated in Figure E2.5.

Figure E2.5: Overview of stage 2 and 3 of the DMU process



The optimisations are independent, and so can be carried out simultaneously to cut down on the amount of time required. As the pipe plan is fixed, the amount of time required for each optimisation is significantly shorter than for a WiSDM run.

All of the results are collected in a large database and in processing stage 2, they are collated into a suitable format for processing in a dashboard. From the 6,000 optimisations there is a vast amount of data, so the process of importing to the Dashboard is defined using a data model. This makes the process efficient, robust and repeatable. The use of this data is defined in Stage 4.

E2.1.4 DMU – Stage 4: Visualisations and reports

By using a dashboard, data can be collated and presented in a simple and repeatable way that allows for more efficient data processing. The following represent a sample of the visualisations that have been created, and an explanation how they have aided our decision making process.

Figure E2.6 shows an executive summary of the scenarios that have been analysed in the DMU, as well as providing the information relating to the scenarios:

- Demand
- Headroom
- Pipe Plan
- Other description (e.g. WFD and RSA)

Average results for the 100 iterations within each scenario are presented for the Whole Life Cost of the solution, the average additional WAFU provided from new supply schemes over the planning horizon and the overall reduction in leakage.

Figure E2.6: Summary overview of the DMU scenarios

Summary

Group
Baseline
Climate Change
Extreme Drought
WFD

Scenario
1 - WiSDM
2 - 2030 High WFD and ...
3 - 2025 High WFD and ...
4 - 2035 High WFD and ...
5 - 2040 High WFD and ...
6 - 2030 High WFD and ...

Demand
High
Low
Medium

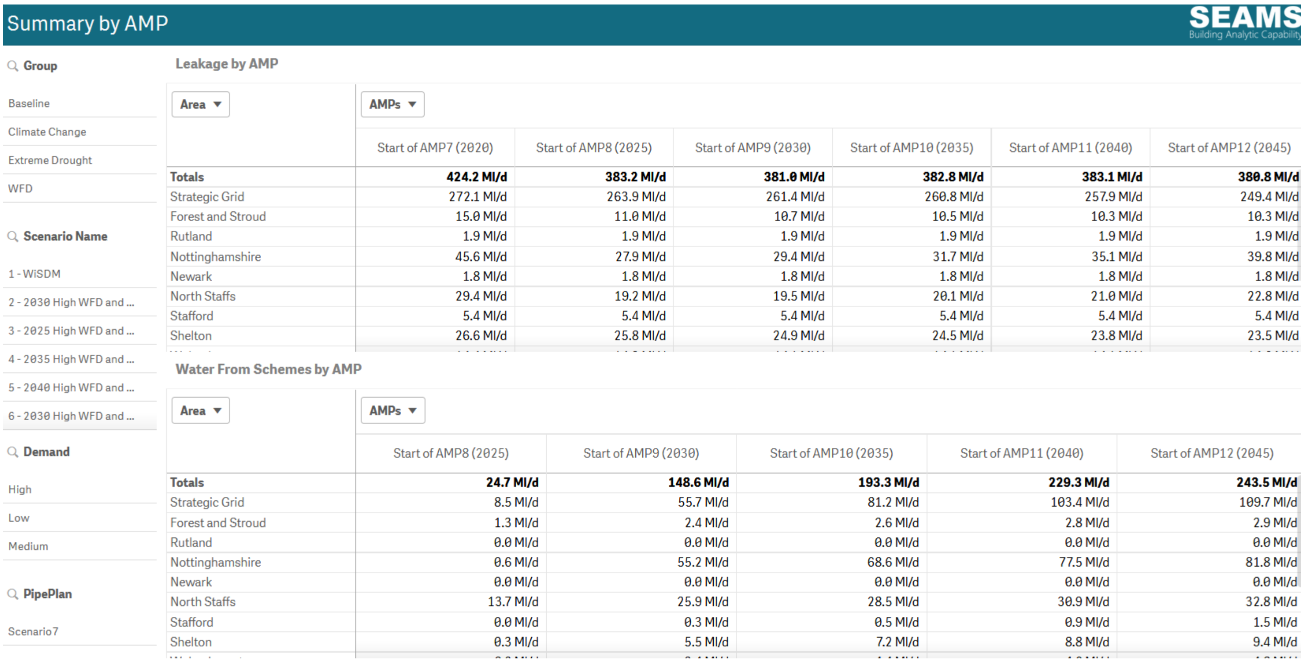
PipePlan
Scenario7

Sce... ID	High Group	Name	De...	Headr...	Pipe Plan	Average WLC £Billic...	Average Additional WAF...	Average % Change in Leakag...
S1	Baseline	WiSDM	Medium	CC Uncertainty	Scenario7	£4.639B	260.5 Ml/d	-8.80%
S2	Alternative Futures	2030 High WFD and Medium Demand	Medium	No CC Uncertainty	Scenario7	£4.564B	268.6 Ml/d	-9.54%
S3	Alternative Futures	2025 High WFD and Medium Demand	Medium	No CC Uncertainty	Scenario7	£4.714B	287.2 Ml/d	-12.08%
S4	Alternative Futures	2035 High WFD and Medium Demand	Medium	No CC Uncertainty	Scenario7	£4.433B	262.2 Ml/d	-8.27%
S5	Alternative Futures	2040 High WFD and Medium Demand	Medium	No CC Uncertainty	Scenario7	£4.387B	264.0 Ml/d	-8.76%
S6	Alternative Futures	2030 High WFD and High Demand	High	No CC Uncertainty	Scenario7	£4.608B	296.6 Ml/d	-12.22%
S7	Alternative Futures	2025 High WFD and High Demand	High	No CC Uncertainty	Scenario7	£4.788B	318.5 Ml/d	-14.90%
S8	Alternative Futures	2035 High WFD and High Demand	High	No CC Uncertainty	Scenario7	£4.475B	287.3 Ml/d	-11.73%
S9	Alternative Futures	2040 High WFD and High Demand	High	No CC Uncertainty	Scenario7	£4.418B	285.6 Ml/d	-11.95%
S10	Alternative Futures	2030 High WFD and Low Demand	Low	No CC Uncertainty	Scenario7	£4.371B	171.3 Ml/d	-6.15%
S11	Alternative Futures	2025 High WFD and Low Demand	Low	No CC Uncertainty	Scenario7	£4.456B	173.5 Ml/d	-7.48%
S12	Alternative Futures	2035 High WFD and Low Demand	Low	No CC Uncertainty	Scenario7	£4.295B	160.6 Ml/d	-5.91%
S13	Alternative Futures	2040 High WFD and Low Demand	Low	No CC Uncertainty	Scenario7	£4.259B	163.1 Ml/d	-5.58%

An example of an AMP by AMP summary for leakage levels by WRZ and additional WAFU by WRZ is presented in Figure E2.7.

Figure E2.7 provided here is an average for 6,000 optimisations. The dashboard has the ability to select individual scenarios or to “drill down” in to specific WRZs and different groupings of scenarios.

Figure E2.7: Summary overview of the DMU scenarios



	Start of AMP7 (2020)	Start of AMP8 (2025)	Start of AMP9 (2030)	Start of AMP10 (2035)	Start of AMP11 (2040)	Start of AMP12 (2045)
Totals	**424.2 Ml/d**	**383.2 Ml/d**	**381.0 Ml/d**	**382.8 Ml/d**	**383.1 Ml/d**	**380.8 Ml/d**
Strategic Grid	272.1 Ml/d	263.9 Ml/d	261.4 Ml/d	260.8 Ml/d	257.9 Ml/d	249.4 Ml/d
Forest and Stroud	15.0 Ml/d	11.0 Ml/d	10.7 Ml/d	10.5 Ml/d	10.3 Ml/d	10.3 Ml/d
Rutland	1.9 Ml/d	1.9 Ml/d	1.9 Ml/d	1.9 Ml/d	1.9 Ml/d	1.9 Ml/d
Nottinghamshire	45.6 Ml/d	27.9 Ml/d	29.4 Ml/d	31.7 Ml/d	35.1 Ml/d	39.8 Ml/d
Newark	1.8 Ml/d	1.8 Ml/d	1.8 Ml/d	1.8 Ml/d	1.8 Ml/d	1.8 Ml/d
North Staffs	29.4 Ml/d	19.2 Ml/d	19.5 Ml/d	20.1 Ml/d	21.0 Ml/d	22.8 Ml/d
Stafford	5.4 Ml/d	5.4 Ml/d	5.4 Ml/d	5.4 Ml/d	5.4 Ml/d	5.4 Ml/d
Shelton	26.6 Ml/d	25.8 Ml/d	24.9 Ml/d	24.5 Ml/d	23.8 Ml/d	23.5 Ml/d

	Start of AMP8 (2025)	Start of AMP9 (2030)	Start of AMP10 (2035)	Start of AMP11 (2040)	Start of AMP12 (2045)
Totals	**24.7 Ml/d**	**148.6 Ml/d**	**193.3 Ml/d**	**229.3 Ml/d**	**243.5 Ml/d**
Strategic Grid	8.5 Ml/d	55.7 Ml/d	81.2 Ml/d	103.4 Ml/d	109.7 Ml/d
Forest and Stroud	1.3 Ml/d	2.4 Ml/d	2.6 Ml/d	2.8 Ml/d	2.9 Ml/d
Rutland	0.0 Ml/d	0.0 Ml/d	0.0 Ml/d	0.0 Ml/d	0.0 Ml/d
Nottinghamshire	0.6 Ml/d	55.2 Ml/d	68.6 Ml/d	77.5 Ml/d	81.8 Ml/d
Newark	0.0 Ml/d	0.0 Ml/d	0.0 Ml/d	0.0 Ml/d	0.0 Ml/d
North Staffs	13.7 Ml/d	25.9 Ml/d	28.5 Ml/d	30.9 Ml/d	32.8 Ml/d
Stafford	0.0 Ml/d	0.3 Ml/d	0.5 Ml/d	0.9 Ml/d	1.5 Ml/d
Shelton	0.3 Ml/d	5.5 Ml/d	7.2 Ml/d	8.8 Ml/d	9.4 Ml/d

A frequency analysis of all of the supply schemes is presented in Figure E2.8. This is a simple proportional representation of how many times a scheme was picked at any point in the planning horizon. In Figure E2.9 a similar analysis is presented but this time the percentage represents the proportion of times that the decision was made to start building a scheme in that year.

This allows analysis of schemes to understand what schemes are being picked in a range of scenarios, as well as the timing of when those schemes are chosen.

Figure E2.8: Summary overview of the DMU scenarios

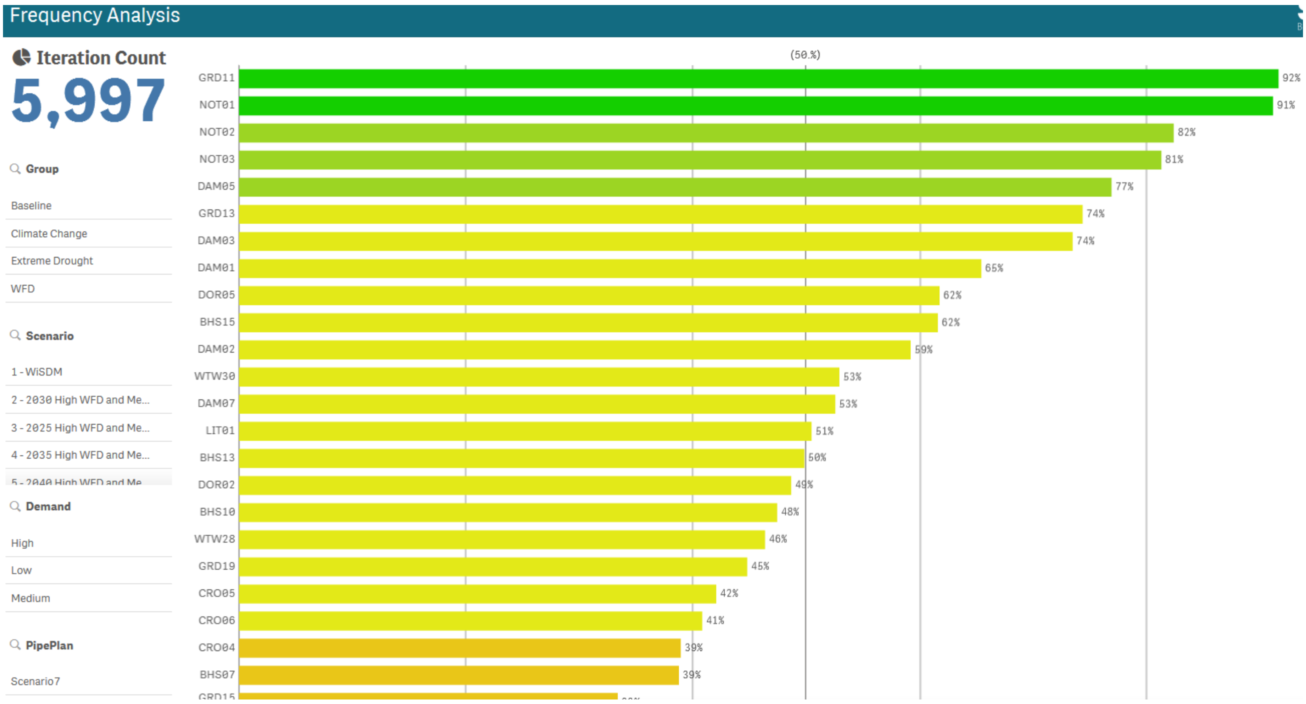
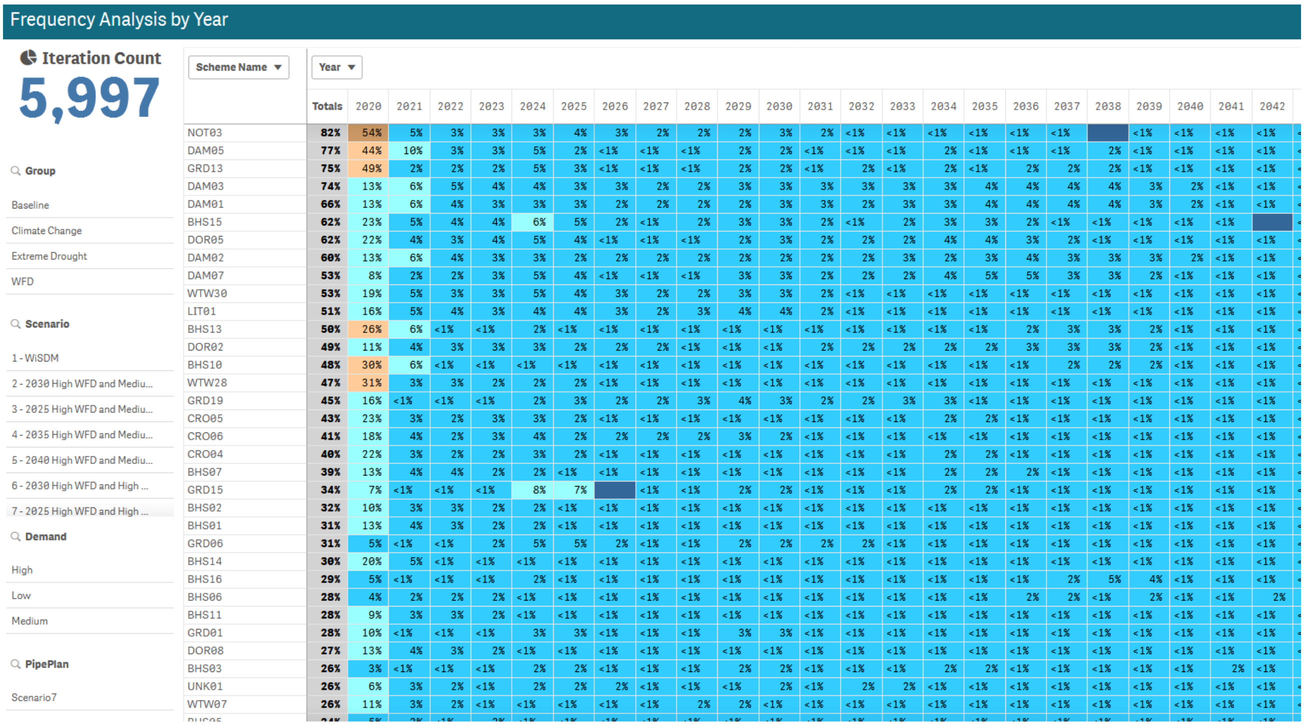
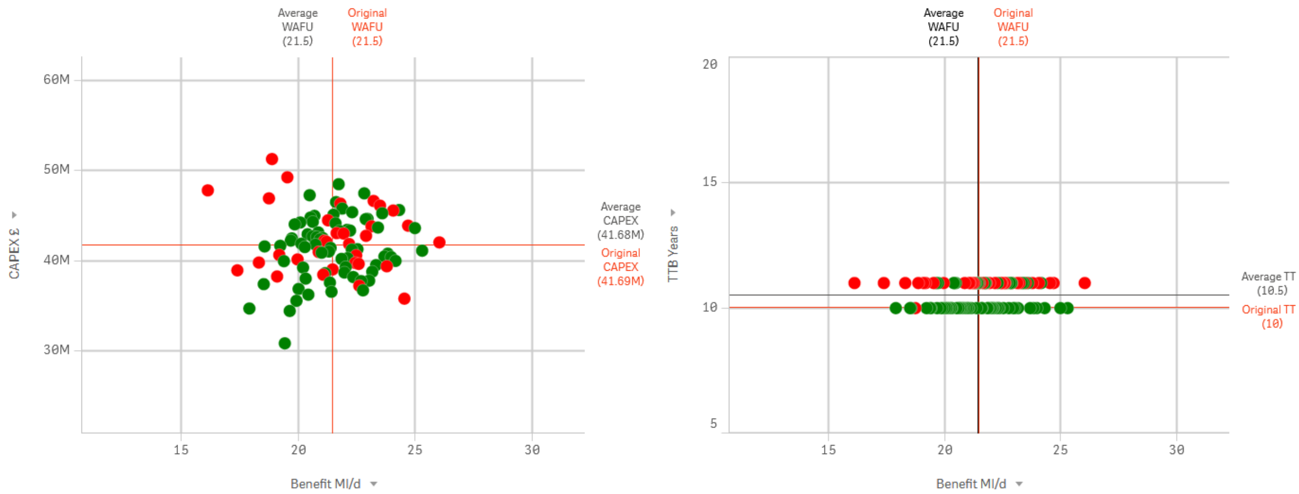


Figure E2.9: Summary overview of the DMU scenarios



Exploring a scheme in further detail is demonstrated in Figure E2.10. In this example, for a single scheme in one scenario all 100 samples are shown. The green/red colour coding denotes whether a scheme was chosen or not chosen. From this example, it can be seen that the main driving factor for this scheme being chosen was the time to benefit (TTB) – when the TTB =10, the scheme was nearly always chosen but when the TTB=11, the scheme was not chosen very often. Note this is for the selected scenario. The spread of the green/red dots also gives the sampling range that was used. The related row from Figure E2.9 is also embedded under the graphs.

Figure E2.10: Scheme level Analysis



Scheme Name	Totals	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	20..
GRD01	68%	55%	2%		1%	1%	3%		1%			1%										2%		1%	

Figure E2.11 is a tabular view of figure E2.10, and allows the user to see the range of each of the variables sampled, as well as being able to filter by whether or not the scheme was selected. The combination of these two figures provides invaluable information to engineers who work on the supply schemes to see when the schemes are chosen, and the conditions under which they are selected.

Figure E2.11: Scheme level Analysis 2

Scenario Name	Scheme Name	% Selected	Minimum TTB	Average TTB	Max TTB	Min Benefit	Average Benefit	Maximum Benefit	Min CAPEX £k	Average CAPEX £k	Max CAPEX £k
6 - 2030 High WFD and High Demand	BHS15	100	3.00 Years	5.51 Years	8.00 Years	13.73 Ml/d	15.00 Ml/d	16.17 Ml/d	£7,329K	£12,094K	£17,442K
6 - 2030 High WFD and High Demand	DOR05	98	4.00 Years	5.49 Years	6.00 Years	7.24 Ml/d	9.00 Ml/d	10.97 Ml/d	£2,398K	£3,924K	£5,772K
6 - 2030 High WFD and High Demand	GRD15	98	5.00 Years	5.50 Years	6.00 Years	3.92 Ml/d	5.00 Ml/d	6.16 Ml/d	£0K	£0K	£0K
6 - 2030 High WFD and High Demand	DAM03	97	3.00 Years	5.49 Years	8.00 Years	1.50 Ml/d	2.50 Ml/d	3.71 Ml/d	£192K	£327K	£476K
6 - 2030 High WFD and High Demand	DAM07	96	5.00 Years	5.51 Years	7.00 Years	7.23 Ml/d	9.00 Ml/d	10.96 Ml/d	£561K	£1,035K	£1,470K
6 - 2030 High WFD and High Demand	LIT01	96	9.00 Years	10.51 Years	13.00 Years	7.91 Ml/d	10.00 Ml/d	12.16 Ml/d	£3,098K	£5,812K	£8,181K
6 - 2030 High WFD and High Demand	WTW30	96	8.00 Years	10.50 Years	13.00 Years	8.66 Ml/d	15.01 Ml/d	22.23 Ml/d	£2,377K	£3,990K	£5,623K
6 - 2030 High WFD and High Demand	GRD11	93	4.00 Years	5.50 Years	7.00 Years	8.52 Ml/d	15.01 Ml/d	23.40 Ml/d	£67,092K	£142,932K	£199,050K
6 - 2030 High WFD and High Demand	NOT01	93	5.00 Years	8.51 Years	12.00 Years	14.42 Ml/d	24.99 Ml/d	35.57 Ml/d	£19,942K	£37,277K	£57,969K
6 - 2030 High WFD and High Demand	DAM01	85	3.00 Years	5.50 Years	8.00 Years	1.48 Ml/d	2.50 Ml/d	3.50 Ml/d	£276K	£531K	£754K
6 - 2030 High WFD and High Demand	NOT02	80	5.00 Years	8.49 Years	12.00 Years	8.02 Ml/d	14.99 Ml/d	21.52 Ml/d	£14,332K	£26,228K	£37,390K
6 - 2030 High WFD and High Demand	CRO06	77	8.00 Years	10.49 Years	13.00 Years	12.66 Ml/d	17.00 Ml/d	21.23 Ml/d	£8,049K	£13,514K	£19,392K
6 - 2030 High WFD and High Demand	DAM02	75	4.00 Years	5.50 Years	8.00 Years	1.50 Ml/d	2.50 Ml/d	3.52 Ml/d	£510K	£985K	£1,378K
6 - 2030 High WFD and High Demand	NOT03	72	5.00 Years	9.49 Years	13.00 Years	14.69 Ml/d	30.00 Ml/d	44.81 Ml/d	£30,607K	£53,657K	£79,404K
6 - 2030 High WFD and High Demand	DOR02	69	4.00 Years	5.50 Years	7.00 Years	1.46 Ml/d	2.00 Ml/d	2.55 Ml/d	£305K	£1,084K	£1,558K
6 - 2030 High WFD and High Demand	GRD01	68	10.00 Years	10.50 Years	11.00 Years	16.13 Ml/d	21.49 Ml/d	26.03 Ml/d	£30,835K	£41,677K	£51,257K
6 - 2030 High WFD and High	CRO05	65	4.00 Years	5.50 Years	7.00 Years	9.15 Ml/d	12.00 Ml/d	14.61 Ml/d	£7,775K	£13,365K	£19,396K

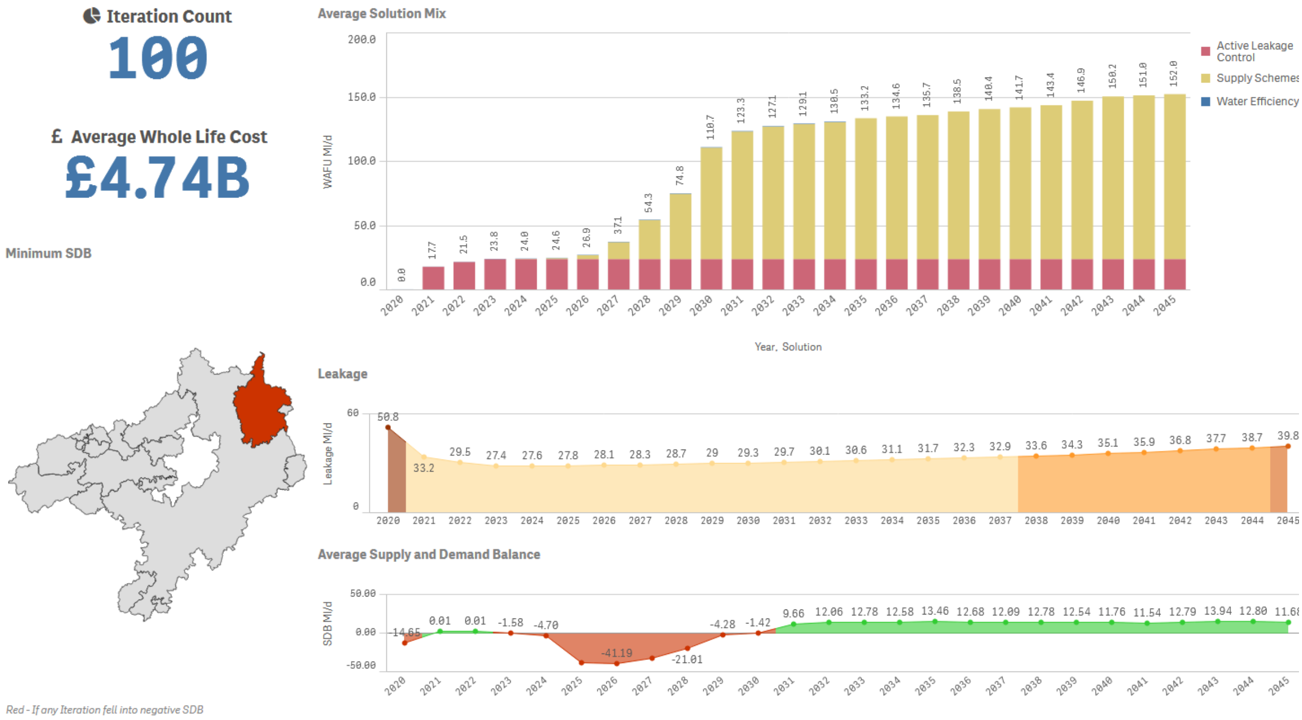
Figure E2.12 shows, for a single scenario, the average solution make up along with the corresponding supply demand balance and leakage profile at a Severn Trent level for the planning horizon. The map of the Severn Trent region by WRZ in the bottom left is coloured red/green – Red indicates that in at least one of the 100 iterations a WRZ has fallen into deficit and an investment solution could not be found. Green denotes that there is always a solution found to keep a zone in surplus.

An individual WRZ (shown in Figure E2.13) can be selected allowing the data just relating to that zone to be viewed. In this example, it can be seen that for this given scenario, on average, there is a SDB deficit through most of AMP 8.

Appendix E: Decision Making

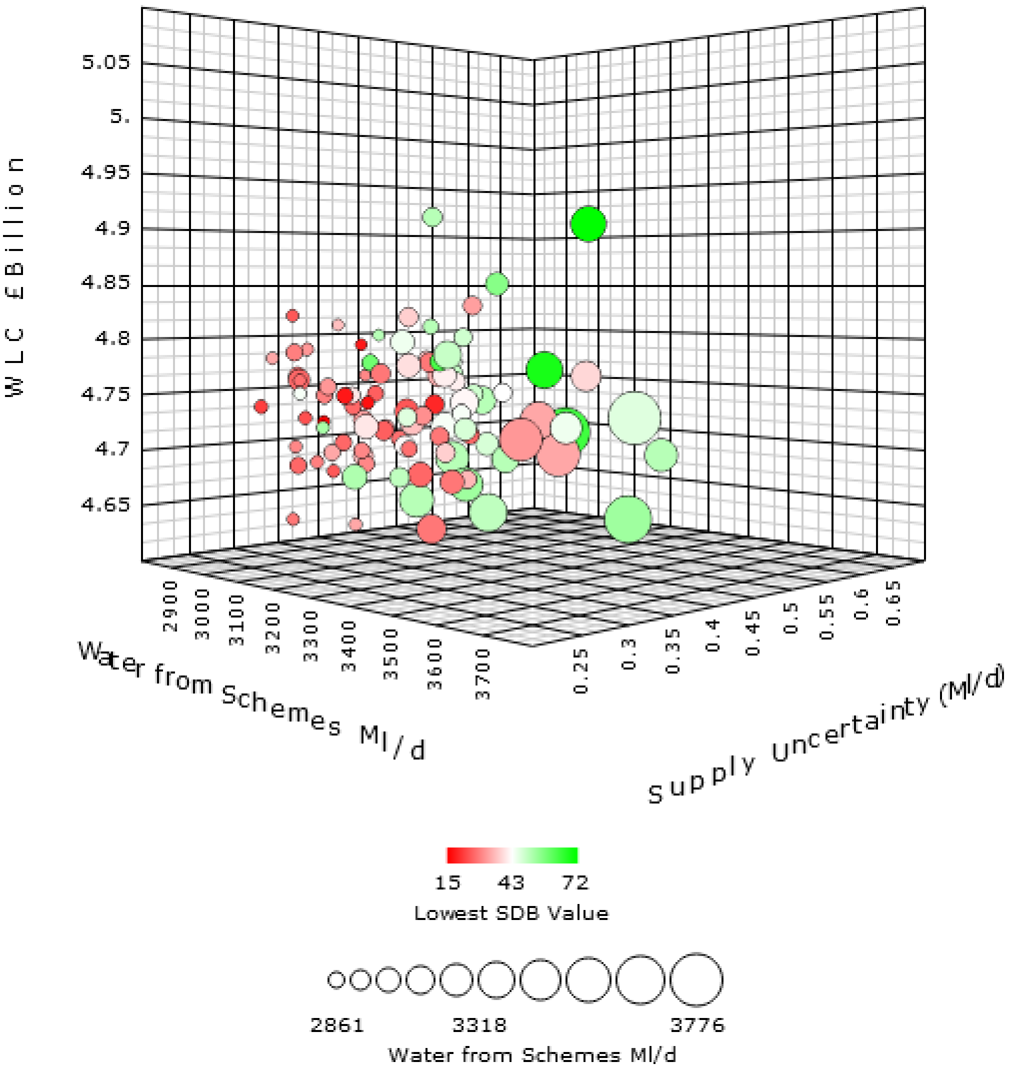
Figure E2.12: Solution Make Up

Figure E2.13: Solution Make Up for individual WRZ



The 3D analysis in Figure E2.14 shows a combination of the whole life cost, the average SDB surplus, uncertainty and the amount of additional water required from supply schemes, presented for one scenario.

Figure E2.14: 3D Analysis



E2.1.5 DMU – Next Steps

The Decision Making Upgrade to the WiSDM model has provided the capability to run a large number of optimisations and consider a wide variety of scenarios and variables quickly and efficiently. In order to make the step to create a truly dynamic plan, using adaptive pathways, via an automated process will require further analysis and work. The building blocks are in place, but completing this process will be a PR19 and WRMP24 enhancement.

What the DMU has provided is the ability to provide compute large amounts of data and present it in a repeatable format to inform the decision making of stakeholders and to provide guidance of what are good decisions not just in terms of a least whole life cost plan but also under a range of alternative futures.

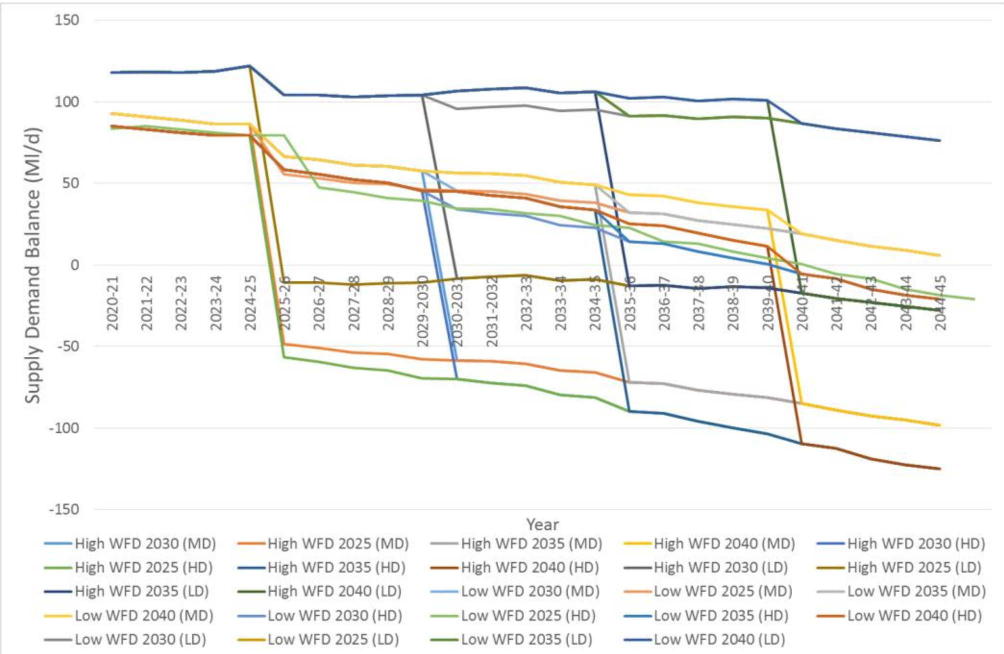
E3 Testing alternative supply / demand scenarios

We have used the DMU to model a large number of supply / demand scenarios representing “alternative futures”, to examine how sensitive our investment decisions are to different planning assumptions. These scenarios used different combinations of potential supply / demand events occurring at different times. These alternative futures were generated by varying those supply / demand factors that have the greatest uncertainty, including sustainability reductions, impacts of Water Framework Directive, climate change and future demand for water. Each scenario used a bespoke “water available for use” (WAFU) profile reflecting the deployable output impacts of the component being investigated and a “high”, “mid” or “low” demand profile.

Our most recent run of the DMU considered 60 scenarios, which are shown in Table E3.1. We included a “benchmark” scenario which represented our best central estimate at the time of modelling (this run was carried out prior to the release of Environment Agency’s WINEP2). Using working assumptions based on the Environment Agency’s first publication of WINEP we assessed the impact of potential sustainability reductions and of varying the WFD No Deterioration impacts. This included varying the severity (either “high” or “low” impact) and the start year so that we could assess the least regrets options available to overcome any resultant supply demand balance deficits. We assumed a “high” Restoring Sustainable Abstraction (RSA) impact across all scenarios as this reflected the envisaged most likely outcome of WINEP2. Under this ‘high’ RSA scenario, we assumed that any future abstraction licence reductions would need to be made to ‘recent-actual’ abstraction volumes. Details of how the sustainability reductions were derived can be found in appendix A4 and A5.

Combining different WFD No Deterioration impacted WAFUs with either “high”, “low” or “medium” demand produced a range of supply demand balance deficits for the DMU to solve. Figure E3.1 shows the range of WFD No Deterioration impacted supply demand balances for the Strategic Grid zone modelled using the DMU.

Figure E3.1 Range of supply demand balance surplus and deficits considered for the Strategic Grid WRZ based on varying severity and start year for WFD impacts



Using this approach, we generated 60 different supply / demand scenarios that we used to explore a wide range of possible alternative supply / demand futures. The full list of the 60 possible supply / demand futures that we have explored using the DMU optimisations is shown in Table E3.1.

Table E3.1 Scenarios modelled using the DMU

		Component			
Run	Scenario	RSA	WFD No Deterioration	Demand	Climate change
1	Benchmark	High	-	Mid	Rank 50
2	High WFD 2030	High	High	Mid	-
3	High WFD 2025	High	High	Mid	-
4	High WFD 2035	High	High	Mid	-
5	High WFD 2040	High	High	Mid	-
6	High WFD 2030	High	High	High	-
7	High WFD 2025	High	High	High	-
8	High WFD 2035	High	High	High	-
9	High WFD 2040	High	High	High	-
10	High WFD 2030	High	High	Low	-
11	High WFD 2025	High	High	Low	-
12	High WFD 2035	High	High	Low	-
13	High WFD 2040	High	High	Low	-
14	Low WFD 2030	High	Low	Mid	-
15	Low WFD 2025	High	Low	Mid	-
16	Low WFD 2035	High	Low	Mid	-
17	Low WFD 2040	High	Low	Mid	-
18	Low WFD 2030	High	Low	High	-
19	Low WFD 2025	High	Low	High	-
20	Low WFD 2035	High	Low	High	-
21	Low WFD 2040	High	Low	High	-
22	Low WFD 2030	High	Low	Low	-
23	Low WFD 2025	High	Low	Low	-
24	Low WFD 2035	High	Low	Low	-
25	Low WFD 2040	High	Low	Low	-
26	Climate Change Rank 1 (2030s)	High	-	Mid	From 2025*
27	Climate Change Rank 2 (2030s)	High	-	Mid	From 2025*
28	Climate Change Rank 3 (2030s)	High	-	Mid	From 2025*
29	Climate Change Rank 4 (2030s)	High	-	Mid	From 2025*
30	Climate Change Rank 5 (2030s)	High	-	Mid	From 2025*
31	Climate Change Rank 6 (2030s)	High	-	Mid	From 2025*
32	Climate Change Rank 7 (2030s)	High	-	Mid	From 2025*
33	Climate Change Rank 8 (2030s)	High	-	Mid	From 2025*
34	Climate Change Rank 9 (2030s)	High	-	Mid	From 2025*
35	Climate Change Rank 10 (2030s)	High	-	Mid	From 2025*
36	Climate Change Rank 15 (2030s)	High	-	Mid	From 2025*
37	Climate Change Rank 20 (2030s)	High	-	Mid	From 2025*
38	Climate Change Rank 30 (2030s)	High	-	Mid	From 2025*
39	Climate Change Rank 40 (2030s)	High	-	Mid	From 2025*
40	Climate Change Rank 50 (2030s)	High	-	Mid	From 2025*

		Component			
Run	Scenario	RSA	WFD No Deterioration	Demand	Climate change
41	Climate Change Rank 60 (2030s)	High	-	Mid	From 2025*
42	Climate Change Rank 70 (2030s)	High	-	Mid	From 2025*
43	Climate Change Rank 80 (2030s)	High	-	Mid	From 2025*
44	Climate Change Rank 90 (2030s)	High	-	Mid	From 2025*
45	Climate Change Rank 95 (2030s)	High	-	Mid	From 2025*
46	Climate Change Rank 10 (2030s)	High	High	High	From 2025*
47	Climate Change Rank 50 (2030s)	High	High	High	From 2025*
48	Climate Change Rank 90 (2030s)	High	High	High	From 2025*
49	Climate Change Rank 10 (2030s)	High	High	Low	From 2025*
50	Climate Change Rank 50 (2030s)	High	High	Low	From 2025*
51	Climate Change Rank 90 (2030s)	High	High	Low	From 2025*
52	Climate Change Rank 10 (2030s)	Low	Low	High	From 2025*
53	Climate Change Rank 50 (2030s)	Low	Low	High	From 2025*
54	Climate Change Rank 90 (2030s)	Low	Low	High	From 2025*
55	Climate Change Rank 10 (2030s)	Low	Low	Low	From 2025*
56	Climate Change Rank 50 (2030s)	Low	Low	Low	From 2025*
57	Climate Change Rank 90 (2030s)	Low	Low	Low	From 2025*
58	Extreme Drought S161	High	-	Mid	-
59	Extreme Drought S64	High	-	Mid	-
60	Extreme Drought S169	High	-	Mid	-

* Climate change impacts implemented from 2025 with step change in 5 year increments

The benchmark DMU scenario used our baseline target headroom assessment which captures all sources of uncertainty in our supply and demand forecasts. All other scenarios used a target headroom profile made up of:

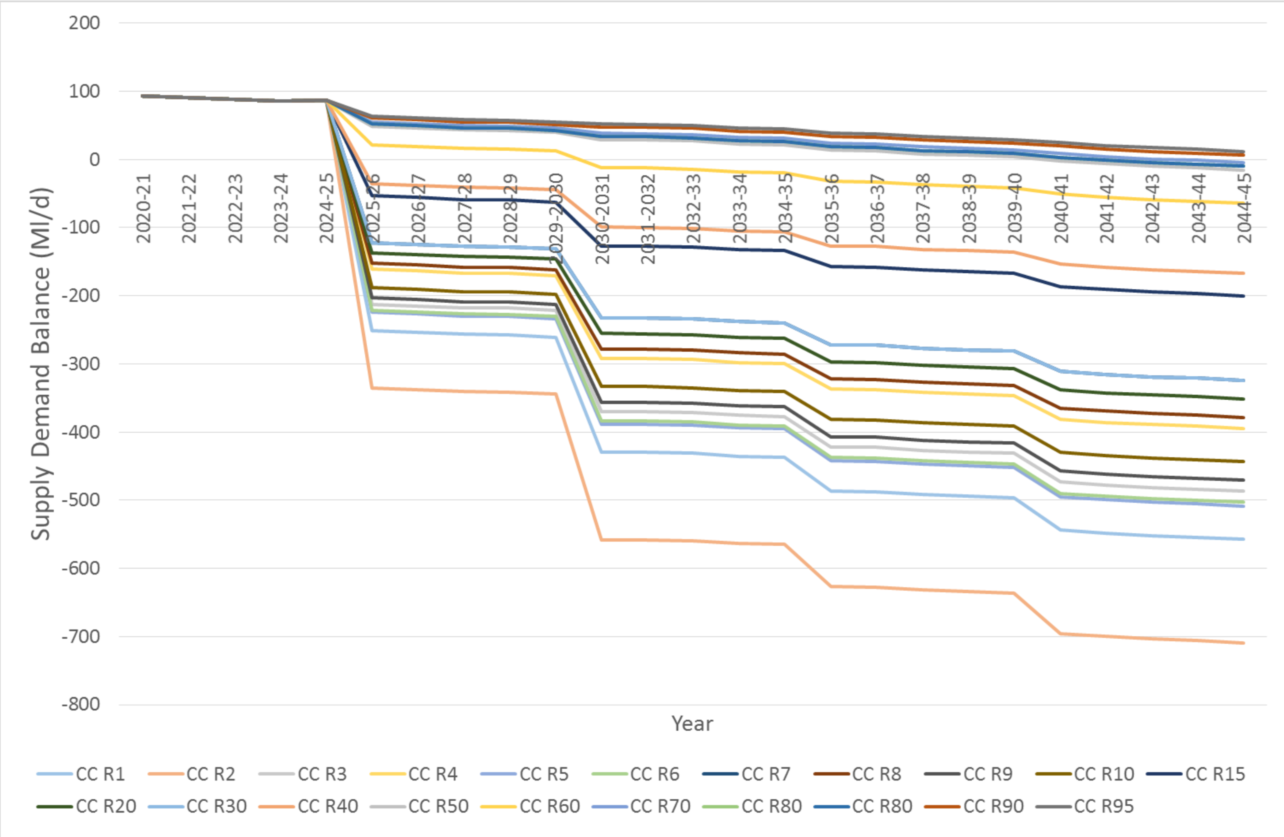
- Supply uncertainty:
  - S5: Groundwater sources at risk of gradual pollution
  - S6: Accuracy of supply side data

- Demand uncertainty, based on the demand forecast:
  - D1: Accuracy of sub-component demand
  - D2: Demand forecast variation

For these scenarios uncertainty around climate change was removed from target headroom. As demonstrated in Appendix C2.3.2, climate change is the biggest source of uncertainty in our two largest water resource zones, the Strategic Grid and Nottinghamshire. Alongside the sensitivity testing of the target headroom climate change uncertainty distribution, we used our DMU model to investigate how climate change is influencing this draft WRMP. As part of our climate change assessment (described in Appendix A3) we modelled the potential impacts of 20, equally likely, UKCP09 projections using our Aquator water resources model. Within the DMU we considered each of the 20 UKCP09 climate projections as individual WAFU scenarios, removing climate change uncertainty from target headroom to prevent double counting the potential impact. This is a key advantage of the DMU as it enables us to consider the different climate change scenarios as individual supply / demand optimisations, rather than combining these climate change scenarios into a large uncertainty allowance.

The climate change projections produced a wide range of impacts on WAFU, particularly for the Strategic Grid. As the driest climate change scenarios caused large reductions in WAFU, we scaled the impacts using five year step changes instead of a year on year reduction. This helped the DMU model to better optimise the AMP by AMP balance of leakage reduction and supply enhancement schemes. Figure E3.2 shows the range of supply / demand balance surplus and deficits for each scenario used in the DMU modelling for the Strategic Grid, which used the climate change impacted WAFUs combined with a "medium" demand profile.

Figure E3.2 Range of supply demand balance surplus and deficits considered for the Strategic Grid WRZ based on 20 UKCP09 climate change projections

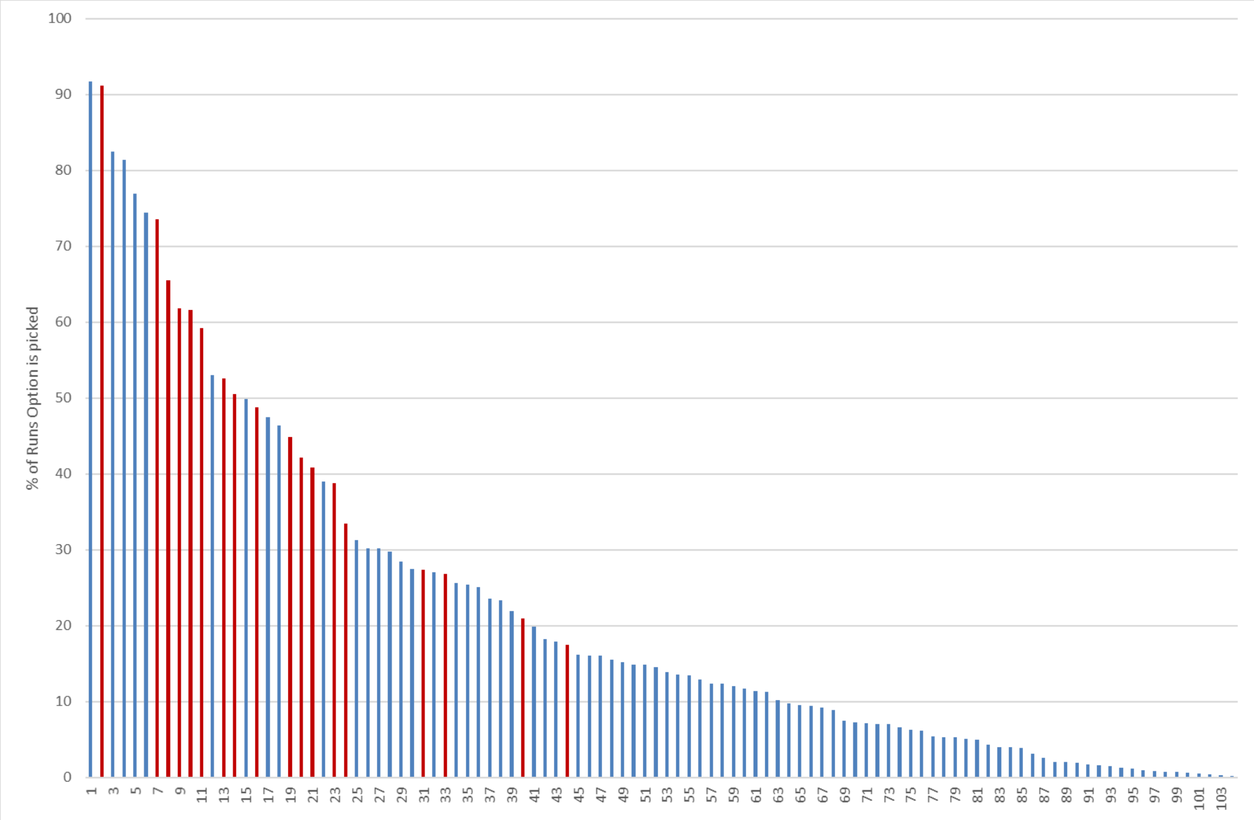


*Each line denotes a different climate change projection e.g. CC R5 is the Climate Change Rank 5 scenario (as described in Table E3.1 and Appendix A3)

Using the DMU outputs we carried out a frequency analysis to understand how often schemes were selected under different types of scenario (climate change, WFD, drought). Each of the 60 scenarios shown in Table E3.1 was optimised using 100 iterations of the DMU, meaning that overall we carried out 6000 iterations to solve all scenarios posed. The DMU outputs gave a good indication of how often schemes were selected relative to each other and how differing scales of supply demand deficits trigger different schemes to be selected and at different times.

Figure E3.3 shows the frequency that schemes selected in our recommended WiSDM S15 optimisation (denoted by red bars) were chosen by the DMU across all 60 scenarios. Those schemes not picked by WiSDM in the S15 optimisation are represented by blue bars. Over 100 schemes, with their uncertainty parameters, were included in the DMU modelling. The majority of the WiSDM S15 "least cost schemes" are in the top 25% most frequently selected by the DMU across all scenarios, indicating that these schemes are also our "least regrets" options.

Figure E3.3 Frequency of schemes picked across 60 alternative future scenarios



The scale of impacts included in our early DMU modelling for RSA and No Deterioration for some of the smaller zones (e.g. Shelton) was higher than the later WINEP2 modelling suggests. This meant that some schemes picked frequently in the DMU selection were not picked by WiSDM in the S15 optimisation as the supply / demand challenge was smaller than expected and the deficits could be resolved using a combination of leakage reduction and customer demand management. For zones such as the Strategic Grid and Nottinghamshire, where the largest supply demand balance deficits exist, the range of SDB challenges posed in the DMU gave an accurate representation of the WINEP2 reductions.

The outputs of the DMU helped focus our efforts for further scheme development and highlighted where additional options for increasing the yield of specific schemes (such as including additional pipelines to move water to a wider area) would be beneficial. They also highlighted that in some zones (e.g. Nottinghamshire) the challenges posed by RSA and WFD No Deterioration were too great to resolve within the Environment Agency's originally proposed WINEP1 timescales.

By running scenarios using different start dates for WFD No Deterioration impacts we were able to demonstrate that a multi-AMP approach to resolving the supply demand challenge would be required. Our solution, which includes local prevention / mitigation measures to prevent environmental deterioration (using measures such as local flow support, hydromorphology measures to improve environmental resilience, catchment and partnership solutions, localised demand management implementing) enables us to move the EA's proposed licence reduction start dates back by 5 years to 2030. This gives more time to implement the least cost supply solutions which require longer to design, build and bring into supply. In conjunction with a programme of leakage reduction and wider customer demand management (water efficiency and metering) this forms a robust plan that safeguards future customer supply whilst at the same time addresses environmental concerns.

Our longer term aspirations for developing the DMU are discussed in section E2.1.5. In the short term, our focus for the DMU modelling will shift from sensitivity testing of the scale of the supply demand challenge to determining optimal resource scheme development requirements. We will be considering questions such as:

- what is the optimal time to benefit and yield required for each scheme and, conversely, as our understanding of the scheme costs and likely zonal deployable output increases improves how does that information impact the frequency analysis?
- what flexibility do we need to build into schemes in the event that we may require them to provide more water in future?
- what impacts do WINEP3 (which the EA will release in March 2018) have on the plan and solutions required?

E4 Stakeholder Engagement and Consultation

We have been working on our draft WRMP since early 2016. During that time we have worked with regulators, stakeholders and customers to understand their priorities and shape our long term water resources strategy. Their views have directly contributed to the proposals set out in this dWRMP18.

A summary of how we have engaged with stakeholders at the different stages of producing the plan is as follows:

- We held our first stakeholder forum in September 2016.
- We issued the WRMP pre-consultation letter in December 2016.
- We completed consultation with planning authorities across the region to get an update on housing growth outlook.
- We published the PR19 Shaping Our Future consultation describing the water resource challenge.
- We consulted on the scope of our Strategic Environmental Assessment.
- We have worked with the regulators and stakeholders to understand priorities.
- We met twice with Ofwat in 2017 to share the emerging WRMP needs and likely impacts.
- We have updated our website to sign-post the WRMP work and to make it easier to access information.
- We held our second stakeholder forum in April 2017.
- We held two Welsh facing stakeholder forum events in July 2017.
- We held English and Welsh stakeholder forums in October 2017 to signpost what solutions are likely to feature in the draft WRMP.
- We held a number of customer engagement workshops during October 2017 to understand their priorities, attitudes to metering and willingness to pay.

Through the water resources stakeholder forum events we gathered hundreds of items of feedback through the interactive breakout sessions and follow up correspondence. The material presented at the forum events along with the stakeholder feedback is visible on our website here https://www.severntrent.com/about-us/future-plans/water-resource-management/water-resource-managment-plan/

Throughout our stakeholder engagement and discussions with regulators, we heard some clear messages that:

- We need to be more ambitious with our leakage reduction targets;
- Improving customer understanding is the biggest issue when tackling water efficiency, they need to be educated on the supply / demand challenges and engagement needs to be tailored to different communities;
- We should explore opportunities for more partnership working;
- We should explore innovative ways of broadening our catchment management thinking beyond just drinking water quality protection to deliver wider benefits such as biodiversity and flow attenuation/slow flow etc;
- New water supply schemes should deliver multi-benefits and we should explore options for water / waste water catchment thinking;

We have used these clear messages to shape our plan, and to guide our thinking as we worked through our different supply / demand scenarios and options. We also used it to guide our more focussed customer engagement workshops, where we have conducted more deliberative research into customer attitudes to drought restrictions, water metering and environmental impacts of abstraction.

This chapter explains how we engaged with our stakeholders and customers through the pre-consultation period, and what key messages we took from our stakeholders to feed into our plan.

During the pre-consultation period we engaged with our stakeholders and customers in a variety of ways:

- written consultation
- external stakeholder technical workshops
- customer research, including willingness to pay
- discussion and scrutiny by our multi-stakeholder CCG (customer challenge group) which we refer to as Water Forum
- Severn Trent WRMP website
- face to face meetings

E4.1 Stakeholder engagement

WRMP External Stakeholder Workshops

Throughout the pre-consultation period we have held a series of WRMP external stakeholder workshops as outlined in the table below. We have held separate workshops in our Welsh operational areas, including the area previously served by Dee Valley Water.

Table E4.1 – WRMP stakeholder workshops

Date	Workshop	Objectives
13 September 2016	Severn Trent WRMP workshop	• Understanding of water supply challenges • Understanding the future demand of water • Decision making considerations • Environmental and social considerations
10 April 2017	Severn Trent WRMP workshop	• Understand how we are acting on stakeholder feedback • Understand how our water resources management plan fits in with our PR19 plans • Understand the potential solutions
15 June 2017	Powys area WRMP workshop	• Understanding water resource needs • Water quality improvements • Catchment management and waste water improvements
28 June 2017	Dee Valley area WRMP workshop	• Understanding water resource needs • Water quality improvements • Catchment management improvements
6 October 2017	English WRMP workshop	• To review and feedback on our draft English WRMP
12 October 2017	Welsh WRMP workshop	• To review and feedback on our draft Welsh WRMP

Appendix E: Decision Making

'Shaping Our Future' Consultation

We aligned our WRMP pre-consultation with the consultation we are carrying out to inform our broader AMP7 business plan for the period 2020-25. Our consultation '*Shaping Our Future'* explained the future challenges we face that effect our business such as climate change, population growth, and future legislation.

One of the key areas we asked for views on in '*Shaping Our Future'* was how we make sure we have enough water to supply our customers. Some of the options we asked for comment on included reducing leakage, reducing demand for water, metering, increasing supply, water trading and connectivity and catchment management.

Seven separate organisations attended the water resources focused workshop held on 3 March 2017. The workshop provided an overview of Severn Trent's emerging supply and demand issues and opportunities, sustainable supplies, drought plans, resilience options, and customer impacts. This was followed by discussions on the following questions:

- How quickly should Severn Trent move away from using water resources that could be unsustainable in the longer term?
- What are your views on Severn Trent's resilience approach to reduce drought?
- Should Severn Trent increase their level of resilience?

Supporting Written Consultation

In addition to '*Shaping Our Future'* we have consulted with stakeholders in line with the guidance set out in the Environment Agency's Guidelines for preparing WRMP's. The written consultations we have undertaken during 2017 include:

- WRMP pre-consultation letter in December 2016.
- Consultation with planning authorities across the region to get an update on housing growth outlook.
- Published the PR19 Shaping Our Future consultation describing the water resource challenge.
- Consulted on the scope of our Strategic Environmental Assessment.

Face to Face Meetings

We have undertaken numerous face to face meetings throughout 2017 to discuss aspects of our WRMP with our regulators, non-governmental organisations and other water providers including:

- Severn Rivers Trust
- Severn Trent Water Forum
- Natural Resources Wales
- Natural England
- Coventry University
- Environment Agency
- Wildfowl and Wetlands Trust

Water Forum

As part of our pre-consultation we have regularly discussed the development of our WRMP with our Water Forums (English and Welsh) and relevant subgroups. These multi-stakeholder groups include representatives from CCW, CCG, Sustainable Blacon, Citizens Advice Bureau, Natural Resources Wales, Confederation of British Industry, Natural England, Environment Agency, East Midlands Councils, and Sandwell Metropolitan Borough Council.

The Water Forum has a remit to scrutinise both how well we engage with our customers, and how well our final business plan reflects the outcome of that engagement.

A Water Forum Investment sub-group has been formed to scrutinise the key elements of our WRMP in more detail on behalf of the full Water Forum. Members of this sub-group include representatives from: Environment Agency, Natural England, ARUP, and the Met Office

E4.2 Customer Research

As part of our PR19 customer research programme we have sought customer views on various aspects of the supply demand balance. As we put together our plan we will continue to seek customer views on how we meet the supply demand balance and drought resilience.

The development of our PR19 plan is consistent with that of any other business plan – it involves:

1. Building on our understanding of the different needs of our customers and legal requirements;
2. developing propositions that deliver those needs, whilst understanding the trade-offs we have made and how they impact our customers;
3. testing and refining our propositions; and
4. looking to continually improve our propositions in terms of our offering and how we deliver it by taking the "pulse" of the business.

Below we describe some of the key research we have undertaken in the first two steps. Steps 3 and 4 will take place in 2018 as we develop and consult customers on our PR19 plan, and then we will define our "business as usual" engagement plan.

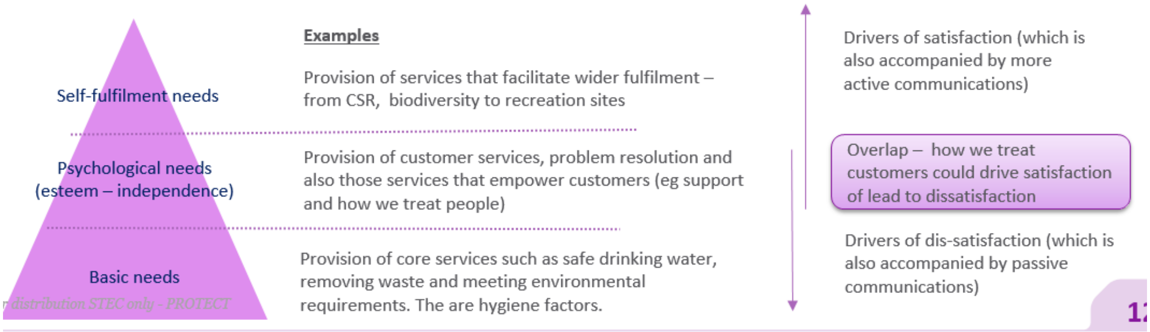
During step one we have focused on developing a broader understanding of what matters to our customers, focusing on their own lives and how they use water, as well as how we deliver our core services to them.

We are gathering insight across a number of different areas, including:

1. A review of our historic customer research.
2. Social media scraping to infer what matters to customers.
3. Staff engagement on the strategic investment challenges
4. Specific research to understand what matters to our customers in their own lives
5. Our quarterly tracker research

We have used this insight to build a rich **understanding of the different needs of our customers**. Our customer challenge group (the Water Forum) has challenged us that not all needs are equal - there is a hierarchy of customer needs and the tools we use to understand those needs will need to be different. We have embraced Maslow's hierarchy of needs to think innovatively about the services we provide and how we can deliver our purpose. Our categorisation of customer needs draws on Maslow's three levels – delivering basic needs (medium and long term), meeting psychological needs and creating opportunities for self-fulfilment. Our understanding of the customer needs is much stronger at the bottom of the hierarchy and less developed at the top (Figure E4.1).

Figure E4.1 – Customer hierarchy



Our **market research review** re-iterates that the top priorities for customers are having water that is safe to drink, a continuous supply of drinking water and wastewater being safely taken away. Despite being the cause of a high number of written complaints, leakage is still scored lower in importance compared to the core service provision.

The **social media scraping** we undertook throughout 2016 analysed over 7 million conversations across online and social media platforms. The key findings were:

- Most conversations tend to be functional, around service issues experienced (such as drainage, leaking pipes and billing issues).
- A personalised community approach and targeted communications can help increase sense of belongingness.
- There is a wide knowledge gap around customer understanding of the role of water companies.
- Customers are open to the idea of saving water but lack information of sometimes face obstacles. There is an opportunity for education on the role of water companies and water saving behaviours.

As well as our research with customers we have driven an internal process to understand the strategic challenges that might affect our ability to meet our customers' needs both now and in the longer term. Through a series of workshops we have engaged extensively with business leaders to expose the areas where we face new or emerging challenges. A long list of over 300 issues has been refined down to five big challenging, which are genuinely long-term:

- Water resources.
- Increasing supply resilience.
- Reducing flooding impacts.
- Delivering a healthy environment.
- Supply pipe adoption.

Our **quarterly customer tracker** is one of the ways we periodically "tap in" to understand customer attitudes and beliefs about water usage and conservation.

Our tracker shows:

- Support from customers for metering (59% of customers surveyed said would prefer to be on a water meter compared to paying a fixed amount, despite the fact that only 41% are metered).
- Metered customers trust Severn Trent more than those not on a meter
- That 24% of respondents are aware of water efficiency products, and 33% are interested in knowing more about water efficiency.
- That 72% of customers are receptive to saving water.
- Reducing leakage was the top priority when prompted with a list of core service aspects to improve, with 58% of customers saying this should be the top priority.

In addition to all these sources of insight we have done an extensive **programme of specific research to understand our customers**, their lives and the role we play in them. Across our region we have spoken to a diverse mix of customer groups using appropriate research techniques, form in depth interviews in customers' homes to deliberative workshops. As well as "general" customers we targeted those with diverse experiences, such as customers with a high engagement with waterways, different faith and cultural groups, those in financially vulnerable circumstances as well as health and wellbeing vulnerabilities, future customers and shared bill payers.

Our research found limited evidence of proactive water saving, beyond the obvious, and that most customers are motivated by financial considerations (rather than environmental ones). There were also mixed views about the benefits of meters, which tells us we need to do more to promote their benefits. Those with water meters tend to be positive about them, reporting saving money on their bills and being more conscious of their own water usage. However, some without meters were concerned about the impact on their bills. There was a feeling that, as their water bill is already relatively low, it wasn't "worth the risk" and a particular issue for customers who use more water than average – living in a larger, multi-generational households, for health and wellbeing reasons or religious reasons (e.g. when doing 'wudhu' before prayer).

Some of the key findings from the research, including further exploration of metering, will be taken forward to **co-creation workshops** with customers. During these sessions we will be working directly with customers to find shared solutions.

Step 2: Understanding the value customers place on improvements to service: Key to developing a robust business plan is the need to understand the value that customers place on potential service improvements. Within the business planning context these values are used to:

- Develop a cost beneficial plan, where improvements in service are positively valued by customers.
- Inform the design the outcome delivery incentives (by informing the calculation of the incentive / penalty rate).
- Understand the overall envelop within which customers might be prepared to pay for an entire plan. This value can be used as a guide for how much customers are willing to pay for the plan as a whole; and to place a cap on the total value of ODI rewards available to the company.

Our **willingness to pay** (WTP) research was conducted in summer 2017. The overall aim of the research is to quantify the value that customers attach to improvements in service. This research is only one part of our strategic approach to customer engagement, designed to ensure that we develop a plan based on the views of customers and other stakeholders.

The research is intended to enable us to show whether the costs of service changes are justified by the benefit to customers. The benefits of potential improvements can be assessed using the results of this willingness to pay survey, and then compared with costs. Our stated preference WTP research is only one part of the rich evidence base we will need to triangulate to inform our plan and the performance levels we will deliver for customers. In addition to the stated preference WTP survey we also conducted a "budget game" experiment with a representative sample of customers, in which respondents were given the opportunity to design their own business plan.

The WTP survey included 15 different attributes, predominantly relating to the core service delivery for customers. With reference to water resources, it included the following attributes:

- Risk of use of standpipes
- Leakage from pipes
- River water flow

Appendix E: Decision Making

The results of our core survey show that the most valued service improvement for domestic customers is reducing leakage. Reducing leakage was also identified as a key priority in a simple question in which respondents were asked to identify their top three priorities from a list of all the proposed improvements. This is a simple question (identifying a top three does not take into account the strength of preference within the top three) however it is reassuring that the most value service improvements in this question correspond well with the stated preference trade off exercise.

It is interesting to note that for non domestic customers reducing leakage did not feature in the top priorities.

Reducing the risk of standpipes was the least valued service improvement, however we recognise the challenge in a WTP survey to provide sufficient context for respondents to understand a complex subject such as drought resilience.

The budget game survey provides an alternative source of information on domestic customers' attitudes towards improvements to service aspects. In the main part of the exercise respondents were asked to build their own plan, with each improvement they chose having an associated cost. Respondents could also improve aspects further (to a second level of improvement) as a second, higher cost. On average, respondents selected around three improvements to build up their preferred business plan. Leakage once again comes out as a top customer priority for customers, with the lowest percentage of respondents being content with the status quo compared to all other attributes and the highest percentage (17%) selecting the highest level of improvement.

As part of understanding how customer value improvements to service, and how they wish us to deliver these, we have undertaken a programme of **deliberative research** through October / November 2017. We have focused this on the key strategic investment areas of our plan, including the supply demand balance, drought resilience and metering strategy. The key objectives for this deliberative research are to:

- Understand customer views on the impact of drought
- Explore levels of tolerance regarding risk and impact of drought
- Explore informed reactions to proposed solutions regarding supply options (e.g. water transfer, effluent reuse, alternative use of sources) and demand management solutions (e.g. metering, behavioural change), and attitudes towards leakage and leakage reduction
- Explore attitudes towards short term versus long term investment options

As part of this programme we undertook a day long deliberative workshop with 24 customers on the supply demand balance and drought resilience, and two half day workshops each with 12 customers focusing on metering and balancing water sources in times of scarcity. In addition to the deliberative workshops we also held in home depths with customers in vulnerable circumstances. The deliberative approach allows us to take customers on a 'journey' so that we could explore the things that matter most to them and their priorities (both spontaneous and when informed about Severn Trent Water activities). This approach allows us to provide information, building participants' knowledge so that they were able to make an informed decision about different options and priorities to address the supply and demand challenge.

During the research we presented customers with eight different options to address the supply demand balance, and went on a journey from understanding their spontaneous perceptions, based on high level description, to having a detailed conversation about what each options entailed and the benefits and concerns of each one.

Some of the key findings from our research are:

- Customers have a strong moral framework when thinking about water usage, resulting in an emphasis on personal and corporate responsibility to use less water.

- Awareness of the supply demand challenge is very low amongst customers, and for most drought is not an issue that they anticipate will affect the UK.

- Because of the emphasis they place on personal responsibility, customers tend to favour demand management approaches over supply side approaches. However they recognise that any solution will need to include a blend of both.

- Customers used four key questions when evaluating the solutions that they were shows:

  1. Does it encourage responsible use of water?

  2. Is it a long term / sustainable solution?

  3. Is value for money?

  4. Does it avoid harming the environment?

- Of the options presented to customers, metering is the once that best satisfied their key questions and which therefore receives the most support. Customers felt that metering can offer real benefits to both the company and customers, especially when accompanied by education on being more efficient. The possibility of saving money through a water meter is highly motivating, and in addition to this customers welcome the enhanced level of personal responsibility that meters bring.

- Customers felt that we should ultimately be moving all customers to a meter – in the short term we should seek to persuade customers to make the shift, ultimately it may be necessary to force them to.

Key Messages

From the WRMP workshops held so far we have collated and analysed over 450 pieces of feedback from our external stakeholders. Any questions we were unable to answer in the workshops have been actioned and published on our WRMP website, along with the slide packs and summaries from each day.

The strong messages coming out of these workshops were:

- Level of customer understanding is the biggest issue when tackling water efficiency, they need to be educated on the company's supply and demand challenges and engagement needs to be tailored to different communities
- Increase levels of partnership working
- Need to be more ambitious with leakage target
- Current catchment management schemes are focussed on water quality, could they be expanded to include attenuation/slow flow etc
- Develop assets to have multi-benefit, catchment approaches
- Top 3 biodiversity duties should be INNS, restoring uplands, and working with farmers/land owners
- Need more innovative, catchment based solutions to demonstrate environmental leadership

In response to these findings, changes we have made in our final plan include:

- We have increased our focus on leakage reduction and water efficiency.
- Our WRMP is a best value plan that delivers low regret solutions and is flexible to accommodate future uncertainty; we are aiming for step changes in our approach to demand management to ensure that our plan is the best long term solution to maintaining the supply demand balance.
- Our stakeholders have influenced the prioritisation hierarchy of our supply and demand solutions.

- Throughout the workshops held so far our stakeholders have shown their support for our WRMP, giving us reassurance that we are working in the right direction.
- The WRMP section of our website has been refreshed; making it more accessible, and is updated regularly with summaries, feedback, and relevant documents from our workshops.