Water Resources Management Plan 2024

Technical Appendix W - Programme Appraisal Methods

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Introduction and Background

What's in this section?

This appendix contains further information relating to Section 10 of the Main Report on Programme Appraisal and Scenario Testing. It focusses on methods used and provides more technical detail in specific areas of the programme appraisal process.

Information on outputs can be found in Appendix X.

The appendix is intended to be read alongside the relevant sections of the Main Report. Please use the contents page to go to your specific area of interest.

The sections are as follows:

- Problem characterisation
- Best Value Planning method and tools
- Best Value Planning metrics
- Examples of system complexity within programme appraisal

Problem Characterisation

Introduction

W.1 Problem characterisation is carried out to guide water resource planners towards the most appropriate method of assessment for the size and complexity of their supply demand planning problem. Analysis of the size and complexity of the planning problem also guides planners to the appropriate length of planning period for their plan, and therefore, as noted, both the adoption of the assessment methodology and the planning period for the plan are informed by outcomes of the problem characterisation.

W.2 UKWIR's WRMP 2019 Methods – Decision Making Process: Guidance[1] provides a decision-making framework for both defining the water resources planning problem and selecting the best method to address it using the full array of feasible techniques. We have followed this approach in producing our plan.

W.3 For each WRZ, the UKWIR guidance requires planners to address a set of questions that can be used to define the risk in each WRZ. Scores are assigned for strategic need, demand complexity, supply complexity and investment complexity, which are then put in a matrix to define an overall high, moderate and low level of concern.

W.4 In Section 10 of the Main Report we explained that both our supply area and the WRSE region as a whole has been classified as being at high risk. Here we explain why this the case for Thames Water.

W.5 WRSE's combined assessment for the region is available on their website.

Characterising the planning problem for our supply area

W.6 Following the guidance, problem characterisation has been carried out separately for each WRZ. We operate six WRZs: London, Guildford, Henley, Kennet Valley, SWA and SWOX, as shown in Figure W-1.

[1] UK Water Industry Research WRMP 2019 Methods – Decision Making Process: Guidance Report Ref. No. 16/WR/02/10

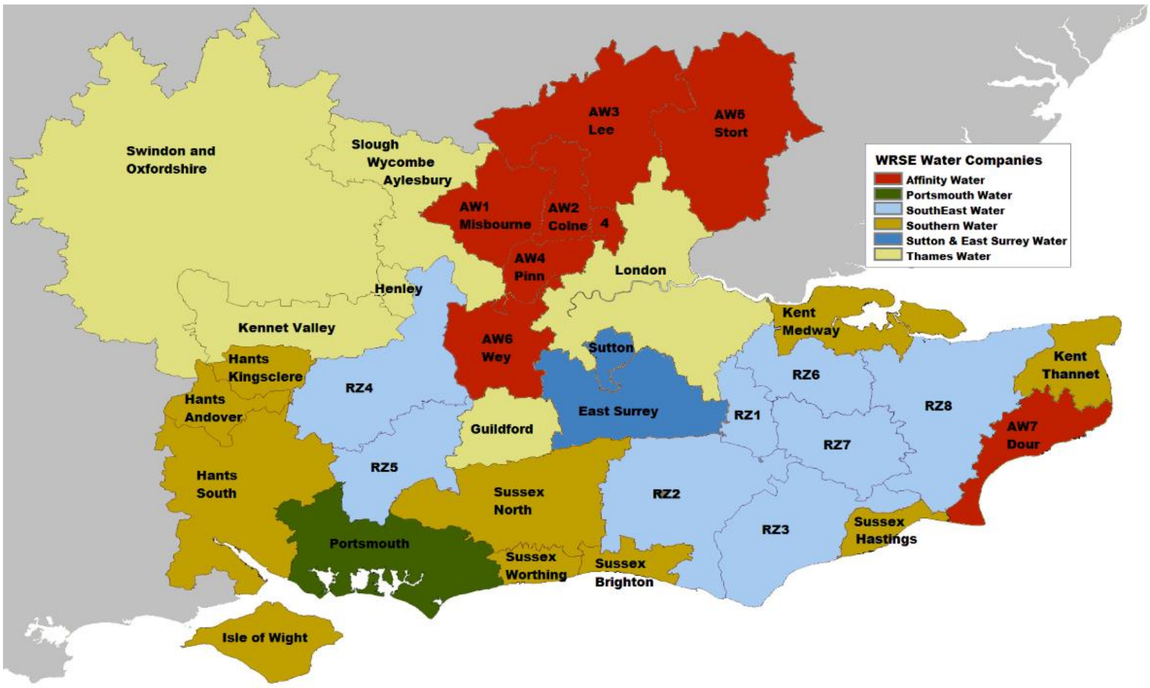


Figure W-1: WRZs in South East England

W.7 We have a number of existing raw and treated water transfers between our own WRZs and with neighbouring water companies. The majority of the transfers are historical, in perpetuity agreements. Most are relatively small and not large enough to affect the integrity of our WRZs. Further transfers are, however, anticipated in the future meaning it is increasingly important to consider risk at a company and regional level.

W.8 For each WRZ, the guidance requires planners to evaluate potential issues on two levels: a high-level assessment of 'how big the problem is', i.e., the scale of need for a new water resource and/or demand management strategy, defined as the strategic need; and 'how difficult the problem is to solve', an assessment of the complexity of issues that affect investment in a particular area, defined as the complexity factor.

W.9 The assessment of strategic need and complexity can then be placed in a problem characterisation summary matrix, in order to define whether an area has an overall low (green), medium (yellow) or high (purple) risk.

W.10 Scoring of strategic need is based on how quickly a zone goes into deficit and how large that deficit becomes over the planning period. Complexity scores reflect the combined complexities of the supply-, demand- and investment-related problems within a given area. As such, the score may reflect the number and novelty of the solutions available, the number and types of solution that will be required and investment challenges this may cause.

W.11 Although the assessment of strategic needs and complexity factors are necessarily subjective, the guidance for the problem characterisation assessment provides detailed "scales of significance" to maximise consistency of problem characterisation between water companies.

W.12 The scores from the analysis are shown in Table W-1 to Table W-4, with the problem characterisation summary matrix as Table W-5.

How big is the problem?				
Strategic WRMP Risks (Score 0-2 each)				
Water Resource Zone	Level of concern that customer service could be significantly affected by current or future supply side risks, without investment	Level of concern that customer service could be significantly affected by current or future demand side risks, without investment	Level of concern over the Investment programme likely to be unacceptably costly or contain contentious options	Strategic Risk Score
London	2	2	2	6
SWOX	2	1	2	5
SWA	2	1	2	5
Kennet	2	1	1	4
Guildford	2	1	1	4
Henley	1	0	0	1

Table W-1: Strategic Risk

How complex is it to solve? (1)					
Supply Side Complexity (Score 0-2 each)					
Water Resource Zone	Concerns about near term supply? (Reliable/ resilient to drought)	Concerns about future supply (climate change/ water quality)	Concerns about near/ medium term step changes to supply (sustainability reductions)	Concern DO may fail to represent resilience	Supply Complexity Score
London	2	2	2	1	7
SWOX	2	2	2	1	7
SWA	1	2	2	1	6
Kennet	0	1	2	1	4
Guildford	1	1	2	0	4
Henley	0	0	2	0	2

Table W-2: Supply Complexity

How complex is it to solve? (2)				
Demand Side Complexity (Score 0-2 each)				
Water Resource Zone	Changes in current or near-term demand?	Forecast uncertainty?	Demand versus critical drought timing critical?	Demand Complexity Score
London	2	2	1	5
SWOX	2	2	0	4
SWA	1	2	0	3
Kennet	0	2	0	2
Guildford	0	2	0	2
Henley	0	2	0	2

Table W-3: Demand Complexity

How complex is it to solve? (3)					
	Investment Programme Complexity (Score 0-2 each)				
Water Resource Zone	Does uncertainty around capital expenditure affect the investment decision?	Do factors such as lead time and promotability affect the decision?	Can wider non-monetisable considerations be properly considered?	Is the investment programme sensitive to assumptions about the utilisation of new resources?	Investment Complexity Score
London	2	2	2	2	8
SWOX	1	2	1	1	5
SWA	1	1	1	1	4
Kennet	1	1	1	1	4
Guildford	0	0	1	1	2
Henley	0	0	0	0	0

Table W-4: Investment Complexity

W.13 The above scores have been combined into the problem characterisation summary matrix, as advised in the guidance, to give an indication of the complexity per WRZ .

WRMP24		Strategic risk score			
		0-1	2-3	4-5	6
Complexity factors score	Low <7	Henley			
	Med 7-11			Guildford Kennet Valley	
	High (11+)			SWA SWOX	London

Table W-5: Problem Characterisation Summary Matrix

Best Value Planning method and tools

W.14 Below is an abridged version of the WRSE Best Value Planning Method Statement that is available on their website.

W.15 We have included this to make our WRMP more standalone but recognising that the programme appraisal process was developed and run via WRSE and endorsed by our Board as described in Section 10.

Method

W.16 The scale and complexity of water resources planning for the Thames Water supply area, and South East of England as a whole, supports the use of advanced decision-making methods to ensure that a robust solution is reached. A method been developed, including the use of a number of decision support tools, to assess and identify a best value, adaptive regional plan.

W.17 The approach was developed in line with key industry guidance and methodologies:

- Water Resources Planning Guideline (April 2022)
- UKWIR (2002) Economics of Balancing Supply and Demand (EBSD)
- UKWIR (2016) WRMP 2019 Methods – Decision Making Process Guidance
- UKWIR (2020) Deriving a Best Value Water Resources Management Plan

W.18 WRSE consulted with and took on board the comments of stakeholders and customers throughout the development of the BVP approach, including:

- Draft Method Statements consultation July-October 2020
- Best Value Planning consultation February-March 2021

W.19 The approach has seven stages, as stepped through in Section 10 of our WRMP24, with the Overall BVP described in Section 11.

W.20 There are a number of key decision points throughout the BVP planning and delivery stages. They can be split into:

- Decisions made in developing the plan itself
- Decision points relating to the delivery of the plan, such as confirming when key policy objectives will be delivered
- Timing of decisions required in the lead up to delivery

W.21 These decisions were made by the WRSE Project Management Board and reviewed by the WRSE Stakeholder Advisory Board (SAB).

W.22 The WRSE Senior Leadership Team (SLT) approved the draft regional plan for consultation. Its decision making was informed by the technical modelling undertaken plus wider input from the member water companies and the views of customers and stakeholders.

W.23 Decision making at all levels is a balance of objectivity (things are objectively calculated) and subjectivity (expert judgement). It is not currently possible, or we would argue, desirable to programme a model (or models) to consider all the variables within water resources planning and have it make all the decisions for us. There is always a balance of evidence as provided by the decision support tools alongside subjective assessment and judgement, taking the views of stakeholders in the round.

W.24 Sensitivity analysis was used to assess any areas of disagreement to understand the materiality of the decision. These areas are brought out as consultation questions in companies WRMPs.

W.25 Three Decision Support Tools (DSTs) are used throughout the process:

- Data Landing Platform (DLP)
- Investment Model (IVM)
- Visualisation Tool (VT)

Decision Support Tools

The Data Landing Platform (DLP)

W.26 The DLP is a data warehouse/integration tool developed in Microsoft Azure with a visualisation function built in Moata[2].

W.27 It was developed in two parts, to deal with input data to and output data from the BVP process:

- The DLP enables all data storage, transfer and transformation to and from the investment model (IVM) and visualisation tool (VT)
- The DLP enables reporting the final problem, options and selection in the Water Resources Planning (WRP) tables for each zone in the region

W.28 The DLP supports the quality assurance process, through either visual or automated verification or likely both. Metadata will be set up to ensure governance of inputs in terms of version control and input personnel, and to track any transformations carried out in the DLP.

W.29 This includes identifying gaps in data, outliers, values outside of set tolerances, and incorrect value types, using a combination of manual and automated verification.

W.30 The table and figure below summarise the input data to the DLP:

Data	Provided by
Baseline supply forecasts	Simulation model (RSS)
Baseline demand forecasts	Demand forecasting models via simulation model
Forecast uncertainties	Simulation & demand forecasting models
Existing transfers	Options appraisal
New supply options and transfers	Options appraisal
Demand reduction strategies	Demand strategies via Options appraisal

Table W-6: Problem Characterisation Summary Matrix

[2] https://www.mottmac.com/digital/moata

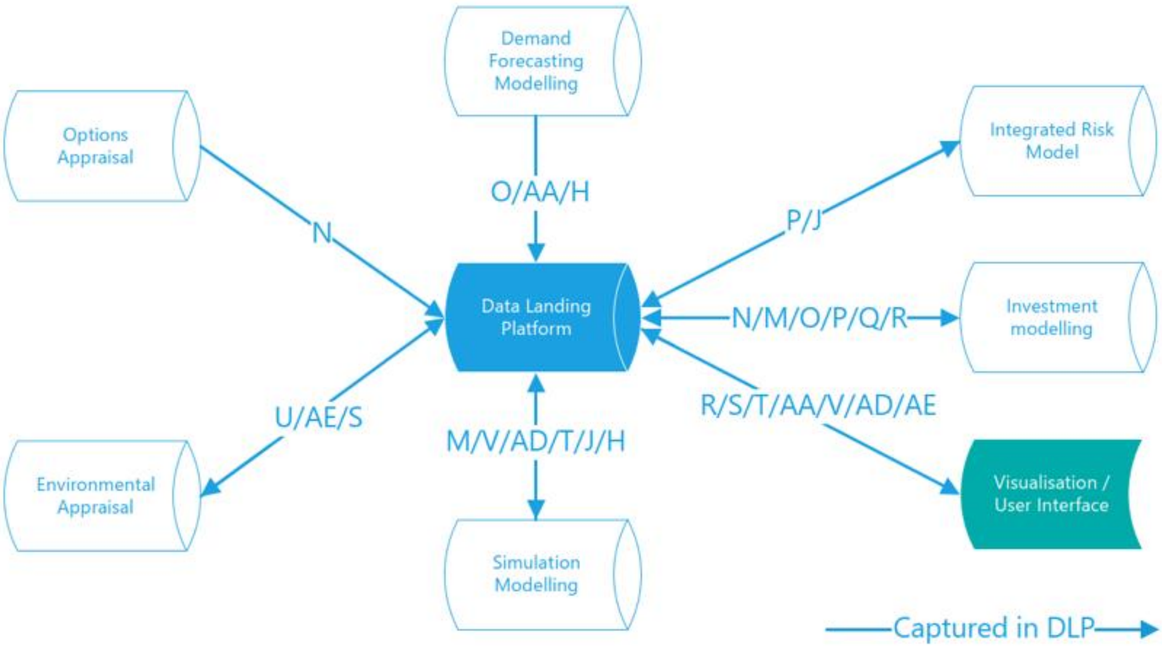


Figure W-2: Flow of Information through the DLP

The Investment Model (IVM)

W.31 The WRSE IVM is a mathematical model for decision support which optimises selection and utilisation of programmes of options to prevent supply-demand deficits within the region over the planning period.

W.32 Planning for future water management requires predictions of water available for use, affected by climate, weather, option operation and legislative drivers, and water demand, also affected by weather, legislative drivers, and population and behavioural change. It is not yet feasible to model all potential futures that may occur across a suitable length of planning horizon in real time, so the IVM uses aggregates of time, space and system performance to reduce the problem to situations that can be solved within a feasible runtime.

W.33 However, the deep uncertainties affecting supply and demand listed above make a solution based on a single future vulnerable to change, and so the IVM has also been developed to explore multiple potential situations that diverge from the 'most likely' path and build programmes that can bridge from one future to another as time unfolds.

W.34 Using branched situations to optimise against a range of futures has encouraged the development of modular options that can more readily adapt from one situation to another.

W.35 The IVM does not determine the best investment programme for the future, but explores a wide variety of pros and cons in terms of investment and carbon costs, environmental impacts, resilience to current and future challenges and customer preference across all the programmes it develops. The programme outputs report metrics representing all of the values of interest together with dates of selection and utilisation volumes for the programmes of options, to aid decision support in selecting a best value plan.

W.36 The IVM is coded in Python[3], and calls specialist routines both from Python and Pyomo[4] libraries and a third-party optimiser, Gurobi[5]. Python is a flexible, open-source programming language with a wide library of established routines. Pyomo is a Python-based open-source software package that supports structuring of a diverse set of optimisation capabilities. Gurobi is a fast, accurate optimisation solver for linear and quadratic programming.

W.37 The primary objective of the model is to select a programme of options and transfers that can ensure supply is not less than demand (total demand plus headroom) in all zones across the region, across all years and planning scenarios for the problem set.

W.38 The IVM does this simultaneously across four planning scenarios:

- Normal Year Annual Average (NYAA): combines 1:2 year annual average water available for use (WAFU), normal year annual average demand, and target headroom. Level of Service and drought options (TUBs, NEUBs, orders, permits) provide zero deployable output (DO) in the normal year scenario
- Dry Year Annual Average (DYAA) (at 1:100 drought resilience): combines 1 in 100 or worst historic drought annual average WAFU, dry year annual average demand, and target headroom. Around 70% of options provide DO in this scenario; for example 15-20% of the drought interventions provide zero DO in 100a-dyaa (i.e. are only available in more severe droughts)
- DYAA (hybrid drought resilience profile): combines an annual average WAFU profile for the maximum drought resilience target. For Thames Water, this means a scenario of 1: 100-year drought initially, moving to 1:200 and then 1:500 by 2040, dry year annual average demand, and target headroom. Around 75% of options provide DO in this scenario; the remainder generally have no DO in any scenario.
- Dry Year Critical Period (DYCP) (hybrid drought resilience profile): combines a critical period WAFU profile for the maximum drought resilience target (with the drought resilience target aligning with that of the DYAA scenario), dry year critical peak demand, and target headroom. Around 75% of options provide DO in this scenario; the remainder generally have no DO in any scenario. One percent of options provide water only in peak, mainly AR/ASR or groundwater schemes

W.39 The IVM solver uses Mixed Integer Linear Programming (MILP) to optimise both capacity of options across all planning scenarios, and utilisation of options over a frequency-weighted combination of the four planning scenarios, for each year and zone across the planning horizon.

Scenario	Weighting
NYAA	0.5
DYAA (1:100)	0.4
DYAA (hybrid)	0.092
DYCP (hybrid)	0.008

Table W-7: Planning Scenario Frequency Weighting for Utilisation

W.40 There are two types of problem that can be presented to the IVM:

[3] www.python.org
[4] www.pyomo.org
[5] www.gurobi.com

- A baseline problem, with a single future pathway defined by four average and peak planning scenarios that may occur under the same combination of environmental, behavioural and legislative drivers, for each zone and year across the planning horizon
- An adaptive problem, where the initial single pathway divides at key points in the future, and each subsequent pathway, defined by four average and peak planning scenarios, represents a different future due to a different combination of environmental, behavioural and legislative drivers, for each zone and year across the planning horizon

W.41 The IVM seeks an optimal investment programme to either of these types of problem, to ensure that the SDBs for each of the four planning scenarios for that situation is satisfied for each year in the planning horizon, in each zone, while minimising or maximising a single objective function, or multiple objective functions.

W.42 The objective functions (i.e. modellable metrics) are listed in Section 10 and comprise cost, environmental and social and resilience metrics. Further information on the calculation of these metrics can be found in WRSE method statements.

W.43 Optimisation works by looking for solutions, calculating the objective function for each, and finding the difference between the best and next best in terms of the objective function. For this type of optimisation this difference is the mixed integer program gap (MIPgap). Optimisation continues, with the solver looking for better and better solutions around the best ones while the objective function values converge, until the best are within the declared MIPgap tolerance. The best is then declared optimal. For a least cost optimisation with a MIPgap of 0.1% and solution costing £15 billion, the optimal solution would be within ±£15 million tolerance.

W.44 The search space for optimisation is partially defined by the size of the objective function values. In order to reduce the search space and decrease optimisation runtime, a scaling factor reduces the size of the search space without reducing the relative variation between solutions.

W.45 Confidence interval and precision are both further model configuration parameters which have been included in the user settings for testing to improve the trade-off between runtimes and optimality.

W.46 The tolerance gap and the objective function(s) are set by the user for each run.

W.47 The first optimisation of any new problem (baseline or adaptive) is always run to find the least cost solution; this run identifies the limits for all best value objectives, allowing best value (pareto) optimisation. Baseline least cost runs form the backbone for problem and option development and testing, with the reasoning for model selection of single-situation outputs easier to trace, providing assurance on model and option behaviour before both are moved into the full adaptive optimisation.

W.48 After the least cost run a single-situation problem can be solved against any of the other objective functions (pareto optimisation); this type of run is usually carried out for testing purposes, either of data or of specific programmes, and is not included in the main steps of best value planning. The first step after single-stage least cost planning is adaptive least cost planning.

W.49 Adaptive optimisation progresses in three stages, each stage is separated by the branch points in the input adaptive problem.

- Stage 1 - The IVM configures and initialises an adaptive run similarly to a baseline EBSD run, except that instead of a single pathway, it solves nine pathways in turn at the beginning of stage one, and stores solutions from all nine. The IVM then initialises progressive hedging (PH) to find a common solution up to the first branch point from all the individual pathway solutions; it iteratively solves all nine situations again and again in turn across this time period looking for a common solution, decreasing the MIPgap for each iteration to reduce the gap between all nine solutions for the first stage until the convergence threshold is reached. The stage 1 solution for the first branch is then fixed and stored.
- Stage 2 - The IVM generates nine new pathways at the beginning of stage 2, each with the stage 1 solution fixed, and the problem for stages 2 and 3 continuing from that fixed start. It solves each iteratively then initialises PH to find an optimal solution for each of the 3 branches in stage 2. Once solutions are found for each of the stage 2 branches they are fixed and stored.
- Stage 3 - The model solves stage 3 as the final stage for each pathway in a simple baseline run with the solution fixed to the second branch point for each situation.

W.50 The adaptive least cost solution optimises against the cost objective function, but calculates and stored values for all other parameters including the other objective functions available for optimisation.

W.51 In previous WRMPs, Average Incremental Cost (AIC) ranking was used to identify the preferred programme. However, water resources investment appraisal has moved on a great deal from simple ranking of schemes based on AIC, recognising that the timing, scale and spatial distribution of need for new water resources, as well as the costs (capital and operational), lead time and emissions of different options, alongside other factors, can mean that simple cost-based ranking of solutions will often not yield either the overall least cost or best value solution. The WRSE investment model is able to consider complexities such as the scale and timing of deficits in multiple water resource zones and in different adaptive plan scenarios, the prospect of shared resources, inter-WRZ transfers which may vary over time, and many other complexities.

W.52 The WRSE investment model, when run in its "Least cost" mode identifies the lowest cost plan for the whole WRSE region, subject to modelled constraints such as policy decisions. The WRSE investment model has been the subject of independent assurance which has confirmed that it achieves this objective. The assurance report includes the quote, "The design of the model accords with the requirements which is to objectively find an optimal solution to the planning problem posed". When considering the infeasibility of manually inspecting the programme-level cost of the many millions of possible option combinations which could solve the WRSE Region's planning problem, this assurance of the WRSE investment model is valuable.

Assurance of the IVM

W.53 Thames Water is part of the WRSE Regional group. The WRSE regional group have all adopted the same decision-support tool in their WRMP investment planning, the WRSE Investment Model (IVM), due to the interconnected plans within the WRSE region. The planning problem within the WRSE region is extremely complex, with inter-company transfers, shared options, option scheduling and adaptive pathways all bringing layers of complexity which must be considered when deriving the best value plan for the region. Due to the complexity of the planning problem, the WRSE IVM decision-support tool is also complex, and the inputs, processes and outputs can be complicated.

W.54 Recognising that the plans for all six WRSE companies are dependent on the outputs of this decision-support tool and acknowledging that confidence in the tool is important, expert independent assurance of the tool was undertaken. The scope of the assurance review included:

- A review of the problem that is faced by WRSE, and a review of the broad approach taken
- A review of the platform and tools used in the model's development
- A review of the development history of the WRSE IVM and developments which have been made in this round of planning
- A review of the mathematical formulation of the model
- A review of the technical implementation of the model
- Validation and verification of the model

W.55 Key comments from the independent expert review include:

W.56 "The size and complexity of the regional planning problem is such that a computer-based model is necessary to ensure that any proposed solution solves the problem."

W.57 "For complex problems, the established practice is to utilise specialist software known as "Solvers" and this is what has been done here. The Decision Lab developers of the WRSE IVM developed an algebraic formulation of the problem and encoded it in the Python language."

W.58 "All models are simplifications of reality, and the level of aggregation within a model is a key design choice. In the case of the WRSE IVM which is a strategic model, the spatial aggregation is to Water Resource Zone (WRZ) level. Forecasts of future supply and demand are associated with an entire WRZ. This represents a significant abstraction from reality as, for example, the model does not concern itself with the details of how water will move within a WRZ. This approach is entirely standard practice for WRMP's. In fact, in some strategic planning settings, further spatial aggregation is undertaken by combining WRZ's. In the case of the WRSE IVM, this was not done, and WRZ's were used as the spatial modelling unit. This was good to see."

W.59 "The WRSE IVM model has been platformed appropriately given the complexity of the planning problem and the regulatory requirements. The separation of model logic from model data supports the need for multiple models runs with different inputs and assumptions."

W.60 "The IVM has been developed to encompass elements of the previously adopted methodologies whilst incorporating more advanced methodologies appropriate to the depth of uncertainty in deficit projections over the planning period. Such advanced methodologies are inherently more complex which brings disadvantages in communication. However, the size of the projected regional deficit, and the uncertainty within the projections does indicate that previous more simplistic approaches may no longer suffice."

W.61 "The documentation of the mathematical formulation shows that the inherent design of the IVM is fit for purpose. It uses established methodologies, specifically those grounded in EBSD, which have been adapted to reflect current thinking around Best Value, and a range of regulatory requirements."

W.62 “The basis of the current methodology was found to consist of a combination of established, known to be reliable methods, combined with cutting edge approaches. This merging of well-established techniques used extensively over several WRMP cycles at both company and regional levels meant that certain parts of the model established high levels of confidence early on. The stochastic elements are well established in academic settings, but most definitely are innovative in this context. These were applied with reference to available guidance in the literature. The mix of old and new was concluded to be appropriate given the scale of the WRSE challenge.”

W.63 “Verification of an optimisation model is challenging and “proof positive” is hard to pin down. The response from client/developer teams should be to develop a tight process which builds knowledge and confidence over time that model solutions are both feasible and optimal within the tolerances set. This was found to be the case in the WRSE IVM development, testing formed part of the process as different functionality was added and new versions of the model released for use.”

W.64 “The design of the model accords with the requirements which is to objectively find an optimal solution to the planning problem posed, using a combination of the various options offered, whilst applying any over-riding constraints e.g., leakage targets.”

W.65 “We saw nothing within the formal design of the model and the method of use which could lead to any bias in the results. The input data - SDB input, offered options, options costs and benefits, interdependencies – are separate and transparent, with good attention to detail as to what settings are in place for each model run.”

W.66 “We were not able to access any formal testing records and this review therefore focused on separate discussions with members of the client and development teams. We are assured that a functional testing mechanism was in place throughout the development period which would ensure that the model was producing the results expected given the inputs and rules it was given.”

W.67 “The combination of team members in both client and developer teams provided the appropriate skills, extensive experience, and expert knowledge to develop a high-quality model. The configuration parameters for the Solver, specifically the MIP-gap has been appropriately set after experimentation. The configuration parameters for the Progressive Hedging heuristic are mostly set to defaults and whilst this is the best place to start, there could be room for performance improvements.”

W.68 These comments from an independent expert give confidence that the WRSE IVM is fit for purpose, both in its formulation and implementation. As such, we should be confident in the model’s ability to derive a least-cost plan. The review recognises that using a complex tool brings challenges in communication but acknowledges that the complexity of the problem which has been posed to the WRSE regional group necessitates the use of such a complex tool. For these reasons, in our programme appraisal, documented in Sections 10 and 11 of the WRMP, we have accepted the outputs of the WRSE IVM as robust and have focussed on interpreting the outputs of the model.

The Visualisation Tool (VT)

W.69 The visualisation tool will be the primary decision support tool to allow appraisal, comparison, selection, communication and refinement of the baseline SDB pathways and trees and final planning investment programme outputs and metrics.

W.70 As such the visualisation tool has to perform two key functions:

- To summarise and simplify, considering the complexity of problem and option combinations that may be output from the IVM
- Support decision making in a way that is accessible to all audiences

W.71 The types of visualisation are covered in Section 10 and run dossiers using the outputs from the VT are available in Appendix X.

Best Value Planning metrics

Cost

W.72 The DLP provides the IVM with cost data for each option for capital, fixed operational and variable operational expenditure calculation. All costs are in GBP except for electricity in kWh, and carbon in tonnes carbon dioxide equivalent (tCO2e) for monetisation.

Capital cost inputs	Fixed operational cost inputs (per year)	Variable operational cost inputs (per Ml)	Total cost inputs and conversion factors
Asset categories	Fixed opex	Variable opex	Price base year
Asset life per category			Option lead time
Capex per category	Fixed grid electricity	Variable grid electricity	Grid electricity cost conversion factor
Weighted average cost of capital (WACC)	Fixed REGO[6] electricity	Variable REGO electricity	REGO electricity cost conversion factor
Optimism bias	Fixed generated electricity	Variable generated electricity	Generated electricity cost conversion factor
Embedded carbon per category	Fixed operational carbon	Variable operational carbon	Carbon cost conversion factor

Table W-8: Option Cost Data Types

W.73 There are several steps to cost calculation for an investment programme in the IVM:

- Option cost indexing
- Capital option cost annuitization (both capex and embedded carbon)
- Calculation of total option cost per year.
- Calculation of total programme cost

W.74 The first two steps are carried out prior to optimisation. The second two steps are part of the cost optimisation.

W.75 All costs are input with a price base year, and the base year may vary depending on when the option costs were last updated. Indexing is carried out to align all option costs to the programme cost base (currently 2021-22) using HMSO's published RPI for operational costs and COPI for capex costs.

W.76 Capex profiles are provided for annual spend across a variety of categories with different asset lives, from granular activated carbon (GAC) with a four-year life to earth embankments with a 250-year life (Table W-9). GAC therefore incurs a renewal cost every four years and embankments every 250.

[6] Renewable Energy of Guaranteed Origin

Capex category	Asset life (y)
Borehole Installation (60)	60
Borehole Screening and Casing (30)	30
Brick/Concrete Office Structures (50)	50
Bridges (40)	40
Building Services (10)	10
Costed Risk	100
Embankment Works (250)	250
Fencing (10)	10
Headworks/Valves (60)	60
ICA (Instrumentation, Control & Automation) (10)	10
Land (Non depreciating)	n/a
Landscaping/Environmental Works (30)	30
Mechanical and Electrical Works on Pumping Stations and Treatment Works (20)	20
Membranes (10)	10
Other Non-Depreciating Assets (Non depreciating)	n/a
Pipelines (100)	100
Planning and Development (Non depreciating)	n/a
Plant and Machinery (15)	15
Power Supply (25)	25
Process-Related Carbon Media Including GAC (4)	4
Raw Water and District Meters (20)	20
Reinforced Concrete Tanks / Service Reservoirs (80)	80
Roads and Car Parks (60)	60
Steel/Timber/GRP Structures (30)	30
Treatment and Pumping Station Civils (incl. Intakes) (60)	60
Tunnels (100)	100
Underwater Assets (60)	60
Water Towers (60)	60
Weirs (100)	100

Table W-9: Capex Categories Used in WRMP24

W.77 Optimism bias is applied to those capex categories where it is applicable (i.e. excluding costed risk).

W.78 Asset depreciation continues from the date operation commences to the end of the asset life, when the asset value is zero. A repeat injection of the initial capex (sum of the capex profile before commissioning) is therefore required for each asset category at the end of the asset lifespan, for example for GAC every four years after commissioning, repeated throughout the cost assessment period (which may be different to the planning horizon, although it is usually the same). The EBSD method recommends annuitizing capex in order to reduce selection bias due to varying asset life lengths, by taking into account the residual cost and benefit of options beyond the assessment horizon.

W.79 In addition to equalising capex requirements for assets of different lifespans for comparison, capex annuitisation shares the cost of long-lived assets across the current and future customer base who will all benefit. It is infeasible and unfair to ask the current customer base to fund the initial capital expenditure of several billion pounds within the next 15 years for strategic resources intended to last up to 250 years. For this reason, funding is sought, and the cost of financing is included in the capex annuitisation for any new resource, spread over the life of the asset and thereby shared by the customer base across its life.

W.80 Annuitisation is a two-stage process; the first step calculates the depreciation, net book value and financing cost for each capex category for an option, the second step averages the initial capital expenditure plus total financing cost across the asset life to give the annualized capex plus capex financing cost per year. The annuitized cost of each asset category is added together to give the total annuitized capex for an option.

W.81 The regulator, Ofwat, fixes the Weighted Average Cost of Capital (WACC) that water companies use to estimate the cost of capex financing; the current rate is 2.917%, and is the percentage return on investment or debt service interest rate that is used for the calculation of the cost of borrowing for future capital investment.

W.82 A worked example is given in Figure W-3 below for calculating the financing cost and annual repayment for capex and financing combined, i.e. the annuitised capex, for the Arkley North pipeline, an option with a single capex category.

The capex value to be annuitised is the sum of the capex profile pre commissioning:

Input data category	Data Entry
Option	Arkleynorth
Capex category	Pipelines (100)
Initial Capex	102,468.09
Asset Life	100
Optimism bias	0.220991667
Cost Base Year	2018
WACC	0.02917

Input data for Arkley North Pipeline.

Optimism bias is added to the initial capex:

Capex including optimism bias	125,112.68

The initial capex, including optimism bias, is indexed to 2021 using HMSO capex inflation indices:

Capex with OB in 2021	137,654.35

The resulting value is depreciated across the asset life and financing cost calculated for the net book value of the previous year at WACC:

Description	Life	Year 0	Year 1	Year 2	Year 3	Year 4	...	Year 100
Capital Expenditure	100	137,654.35						
Remaining Asset Life	100		100	99	98	97	...	1
Depreciation	100		1,377	1,377	1,377	1,377	...	1,377
Net Book Value	100	137,654	136,278	134,901	133,525	132,148	...	-
Debt Service	100		4,020	3,979	3,939	3,899	...	40
Annuitised	100	3,406.39						

Arkley North capex financing and annualisation calculation

The annuitised capex is the capital expenditure plus all debt service costs over the asset life, divided by the asset life, and is allocated annually from the year an option is selected until the end of the assessment period. This means assets with a shorter lifespan will have been renewed, and assets with a lifespan beyond the end of the horizon will not yet have been fully paid for.

The financing cost for the Arkley North pipeline is £202,985 over the 100-year asset life.

Figure W-3: Capital Cost Annuitisation Example

W.83 For any year, the total option cost depends on whether the option is selected, commissioned and/or utilised. An option may be selected in year X. Commissioning occurs in year X + lead time. Utilisation can occur in any planning scenario in any year from year X + lead time depending on whether the option is required; utilisation is optimised for all selected assets by cost minimisation.

- Selected: annuitized capex and monetised embedded carbon
- Commissioned: Capex plus fixed operational (fopex) including monetised electricity and carbon costs
- Utilised: Capex plus fopex plus variable operational (vopex) including monetised electricity and carbon costs per Ml

W.84 Electricity costs are calculated by multiplying the kWh by conversion factor depending on generation type.

W.85 Carbon costs are calculated by multiplying the tCO2e by the carbon conversion factor.

W.86 The annual option costs are summed for each year and discounted using the applicable declining discount rate (STPR, LTDR and IGEQ) to give the net present value (NPV) of an investment programme for any situation. These situation NPVs are minimised for the cost, intergenerational equity and long-term optimisations.

Programme-Level Costs

W.87 According to the options selected and their utilisation, using the methods described, the IVM is able to calculate a programme-level cost for any programme of options. It is this regional-scale, programme-level cost which is used in our programme appraisal, as opposed to examination of individual option costs.

W.88 When considering the scale and complexities in the WRSE regional planning problem, interpreting the investment model outputs can be challenging. For example, there are many examples when low AIC solutions may not be part of an overall lowest cost plan. Two hypothetical examples of this are highlighted here, which are of relevance to our decision-making process.

Example 1 – large magnitude planning problem

W.89 The problems considered in WRMP24, in particular environmental destination and 1 in 500-year resilience, are exceptionally large. In many cases, the large planning problem means that a large option must be selected, and as such the selection of small options is not efficient. Furthermore, while large options can be expensive, in many cases delivering larger variants of large options is much more efficient than the delivery of smaller variants of large options, and as such the marginal cost of upsizing large options can be smaller than the marginal cost of delivering small options. SESRO is an excellent example of this: the 150 Mm^3 SESRO option is only c.25% more expensive than the 75 Mm3 SESRO option, despite delivering c.100% more Deployable Output benefit.

W.90 A useful hypothetical example is explained here. A WRZ has a future deficit of 100 Ml/d, with options available as per the table below. In this example, the smaller schemes have the lowest price per Ml/d benefit gained (£2m per Ml/d DO benefit as compared to £2.5m per Ml/d DO benefit for the larger SRO variant and £4m per Ml/d DO benefit for the smaller SRO variant) but would not be part of an overall least cost plan.

W.91 The feasible programme solutions to this planning problem are:

- Smaller SRO variant + 5 small schemes. Cost = £300m
- Larger SRO variant. Cost = £250m

W.92 As such, in this example, the cheapest individual solutions do not feature in the cheapest overall solution.

Option	DO benefit (Ml/d)	Cost (£m)
SRO – smaller variant	50	200
SRO - larger variant	100	250
Small scheme 1	10	20
Small scheme 2	10	20
Small scheme 3	10	20

Small scheme 4	10	20
Small scheme 5	10	20

Table W-10: Programme-level cost example 1

Example 2 – shared solutions

W.93 In the WRSE region, not only are the planning problems large, but they are spatially distributed across the region and can involve shared solutions. This can mean that the overall planning solution can be different to the optimum solution for a single WRZ.

W.94 In this example, WRZ1 has a deficit of 60 Ml/d while WRZ2 has a deficit of 20 Ml/d. As such, feasible combinations of solutions (tabulated below) are:

- SRO smaller variant + Interconnector 1 + small scheme 1 + small scheme 3 + small scheme 4. Cost = £320m
- SRO larger variant + Interconnector 1 + Interconnector 2. Cost = £270m

W.95 Clearly, when considering WRZ2 in isolation, the adoption of the SRO would not be the most cost efficient solution (small solution 3 and 4 together cost only £40m). However, a larger solution being required for WRZ1 means that the shared use of a larger solution is the most efficient solution overall.

Option	WRZ benefit / connection	DO benefit / capacity (Ml/d)	Cost (£m)
SRO – smaller variant	N/A (interconnector required)	50	200
SRO - larger variant	N/A (interconnector required)	100	250
Interconnector 1	SRO to WRZ1	100	10
Interconnector 2	SRO to WRZ2	100	10
Small scheme 1	WRZ1	10	20
Small scheme 2	WRZ1	10	20
Small scheme 3	WRZ2	10	20
Small scheme 4	WRZ2	10	20

Table W-11: Programme-level cost example 2

W.96 While these examples are intended to be illustrative, they are useful when reflecting on the TW/WRSE programme appraisal problem and the options selected.

Interpreting Model Outputs

W.97 Interpreting the outputs of the WRSE investment model can be challenging. There may be cases where options with low Average Incremental Costs (AICs) are not selected as part of a least cost/best value plan, and conversely there may be cases in which options with high AICs are selected. In order to ensure transparent decision making, in a response to a data request from Defra, we highlighted those feasible options with a low AIC which have not been selected in our preferred programme, and highlighted those options with a high AIC which have been selected in our preferred programme.

W.98 We identified the SESRO option as being the highest-AIC SRO which is selected. As such, we interpreted the reason for the non-selection of any option with an AIC less than SESRO (including those which bring WAFU/capacity benefit but are not selected). For completeness, we have then also interpreted the reason for the selection of any option with an AIC higher than SESRO (including those which do not bring WAFU/capacity benefit but are selected). The selection of SESRO over its alternatives has been discussed throughout Sections 10 and 11 of the WRMP.

Environmental metrics

W.99 There are four environmental metrics: SEA benefit and dis-benefit, natural capital and biodiversity net gain. Section 9 of the WRMP describes these metrics and assessments used to calculate them in more detail.

W.100 In each case, to develop a programme-level value for each metric, the option-level metric values (of all selected options) are cumulatively summed per year.

Social metric

W.101 Our social metric (beyond those in the SEA assessment) is based on customer research into the relative preference for option type (CUPR).

W.102 This research, for WRSE, provided preference scores for each option type as below:

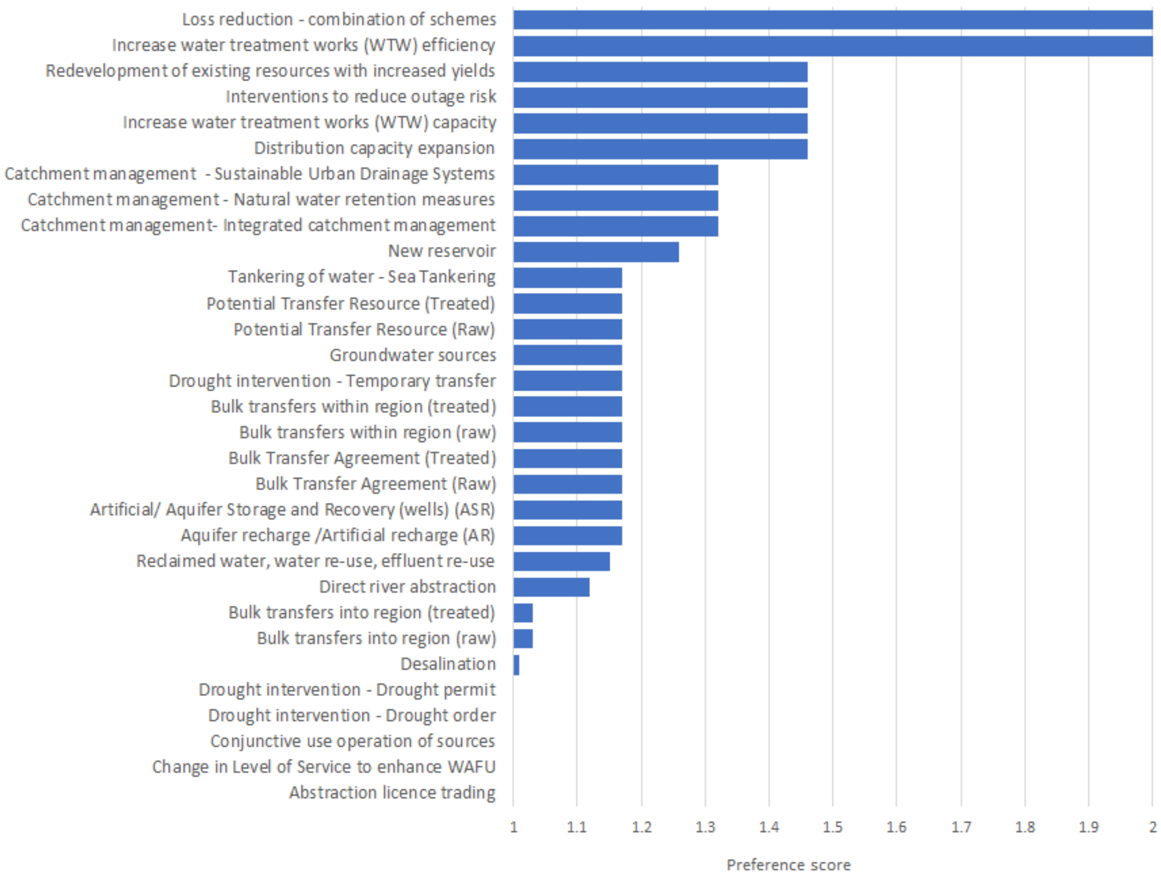


Figure W-4: Relative Customer Preference by Option Type

W.103 The overall programme CUPR score is calculated as the sum of scores of all commissioned options per year for each pathway, and CUPR can be maximised or set to reach a target when required.

W.104 Further information on the research is available in the WRSE Method Statement on Customer Engagement.

Resilience metrics

W.105 The IVM contains three resilience metrics (Reliability, Adaptability and Evolvability). All three, at plan-level are the sum of scores from a number of sub-metrics.

$$Reliability = (R1 + R3 + R4 + R5 + R6 + R7 + R8) - BaselineScore_r$$
$$Adaptability = (A3 + A4 + A5 + A7) - BaselineScore_a$$
$$Evolvability = (E1 + E2 + E3 + E5) - BaselineScore_e$$

W.106 The baseline scores referred to in the formula are zero.

W.107 The overall sub-metrics are each calculated as the sum of scores of all selected options per year for each, weighted by the proportion of deficit to 2050 satisfied.

W.108 Further detail on resilience metrics considered can be found in the WRSE Resilience Framework document.

Best Value Plan aggregate metric

W.109 We use a BVP Aggregate metric (measured as a percentage) to bring together the values for all BVP metrics (environment, social and resilience) into a single value. We use this to determine the relative performance of run within the Cost vs BVP metric plots as used in Section 10 of the WRMP.

W.110 The aggregate metric is calculated as follows: The score for each individual BVP metric is normalised into a percentage scale. The normalisation process is to make the worse run output score 0 and the best score 100 and the other scores for the metric scaled between these two points. This is done looking at the outputs of all the relevant runs within a selected folder in the IVM database. We average the scores across the pathways per metric and then we average the metrics to established to single percentage value for each run.

W.111 This approach is also used to aggregate the scores for the resilience and the environmental and society runs.

System complexity within Programme Appraisal

Interconnectors and System Reinforcements

W.112 As described in the earlier section of this chapter entitled "The Investment Model (IVM)", the IVM uses complex methods to ensure supply-demand balance in all water resource zones (WRZs) across the WRSE region.

W.113 The IVM can consider complex scenarios, such as optimising programmes for multiple supply-demand balance scenarios simultaneously. As well as this form of complexity, the investment model can ensure optimal solutions when considering "system" complexity. Water resources solutions can involve several elements, including raw water sources, treatment, tunnels and pipelines. Different solutions require different combinations of these elements, and some solutions may be flexible and incorporate different elements when used in different ways. Ensuring that all necessary components of a solution are considered when deriving an investment plan, while also ensuring efficiency, can be a complex modelling task.

W.114 The simplest representation, which is adopted wherever possible, is that an option should encompass all the assets required to deliver water to consumers. For example, a new groundwater option for use in the London WRZ may incorporate the costs associated with new boreholes, a raw water interconnector to transport water to a treatment facility, a new treatment works to treat water, and a treated network interconnector to transport water into the supply network. In this way, all costs associated with obtaining and transporting water would be considered within a single "option" or "solution".

W.115 However, in many situations, complexities mean that this level of aggregation is not possible. In these circumstances, the WRSE investment model is able to ensure proper consideration of system complexity via the following means:

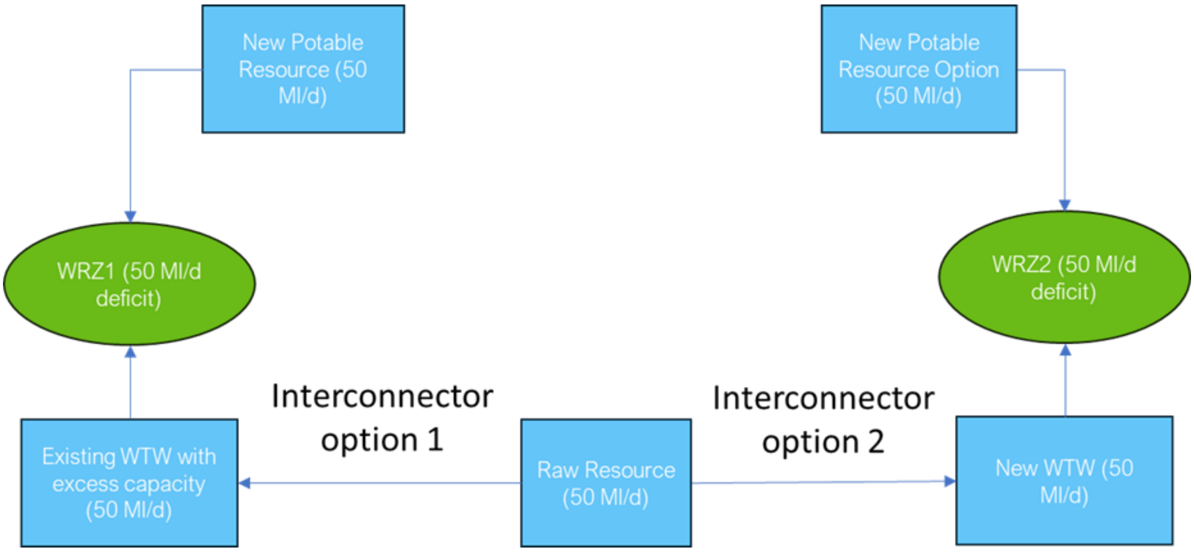
- Dependencies
- Groups
- Phasing
- Differentiation between "raw" and "potable" water
- Differentiation between "resource", "interconnector" and "treatment" options

W.116 The inclusion of these factors ensures that the overall system benefit is considered. This means that our decision making process has taken account of the combined cost of developing new supplies, and ensures that interconnector benefits are not double-counted.

W.117 These complexities are best considered through examples. We have detailed six hypothetical examples below, which highlight how the investment model is able to use these features to deal with different aspects of complexity to identify the optimal plan overall.

W.118 When comparing interconnector solutions with other solutions in our plan, it is important to bear in mind that, aside from the Severn-Thames Transfer, no interconnectors included in our plan yield a WAFU benefit on their own. All either require a resource input, support in some form, or are "system reinforcement" option (see Section 7 for further details). As such, aside from the Severn-Thames Transfer, comparison should not be made between resource options (with benefits stated as WAFU benefit) and interconnectors (with benefits stated as capacity).

Example 1 – Treatment and Interconnectors



W.119 In this example, two WRZs each have a deficit of 50 Ml/d. There are options available for each WRZ which deliver potable resource (i.e., they include all option elements), as well as a raw water resource option which could be used either in WRZ1 or in WRZ2. If the raw option were used in WRZ1 then an interconnector would be required but a new WTW would not (with there being excess capacity at an existing treatment works), while if the raw option were to be used in WRZ2 then a new WTW and interconnector would be needed.

W.120 It would not be possible to define a single option which incorporates all assets required to utilise the raw water resource, because the raw water resource could be used in different WRZs but could not be used in both zones at the same time. Instead, the IVM would include separate elements to represent the raw resource, each potable resource, each interconnector and each treatment element.

W.121 Given that, according to the costs of the different options and the timing at which different deficits occur, there may be different optimum solutions. In this case, splitting options into resource, interconnector and treatment options is required to ensure the overall optimal solution is identified. eg, if the new potable options were very expensive and high opex requirements, with the potable option in WRZ1 being extremely expensive, and if WRZ2's deficit occurred later in the planning period than the deficit in WRZ1, one (complex) optimum solution could exist whereby the raw resource and interconnector 1 are developed.

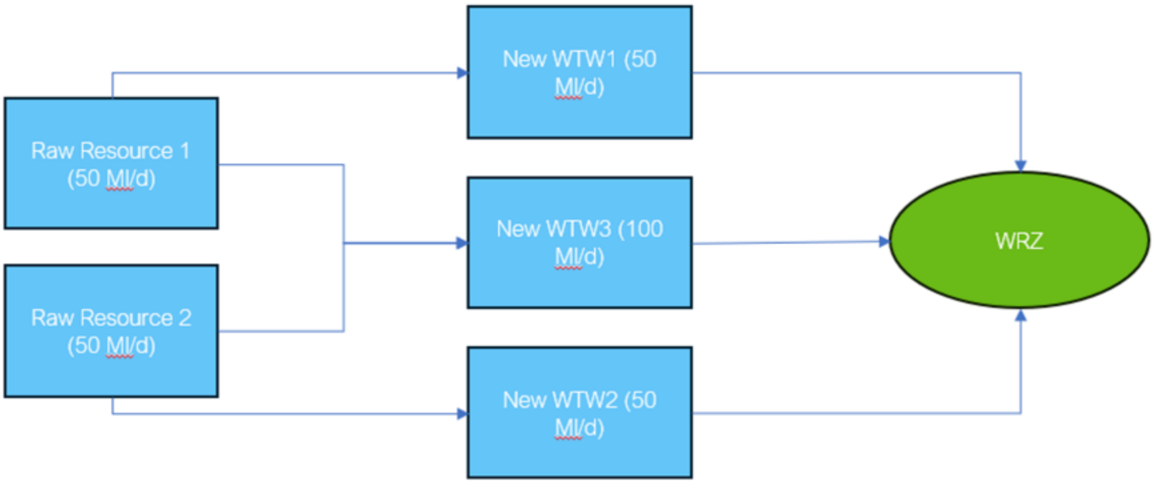
W.122 In this example, the IVM would use the following features to ensure the correct solution:

- Water from the "raw resource" element would be defined as raw, and so the model would require that resource goes through a treatment element, before satisfying demand

- Water from the "potable resource" elements would be defined as potable, and so the model would be able to satisfy demand with water from these elements without including treatment
- The "raw resource" would be allocated a "resource" value
- The "potable resource" options would be allocated a "resource" value
- The "interconnector" elements would have a capacity, but would not be allocated a resource value (i.e., constructing interconnector 2 and the WTW would not allow for the demand to be satisfied)

W.123 The inclusion of these factors in modelling ensure that, where interconnectors are required they are constructed, but that the benefits of interconnectors are not double counted.

Example 2 – Treatment choices



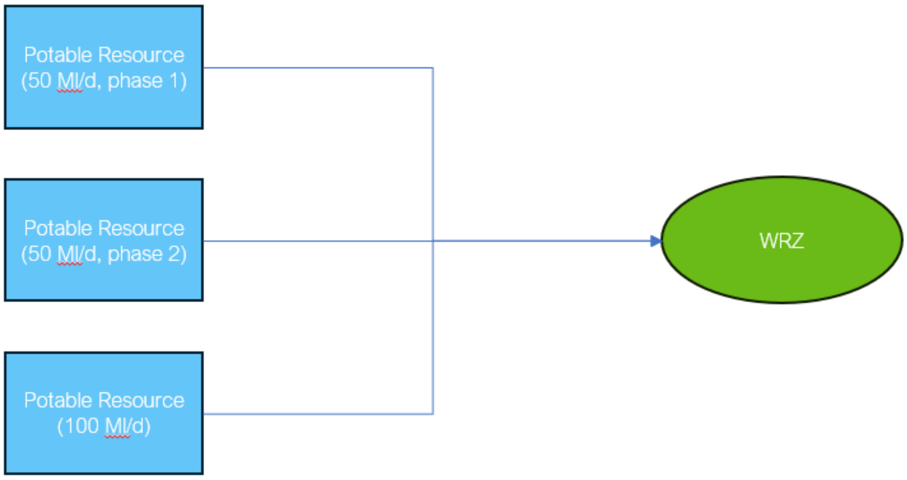
W.124 In this example, two different raw water resource options could be built with different treatment options.

W.125 Depending on the profile of need, it could be that any of the following is the optimum plan:

- One raw water option is constructed with a small WTW
- One raw water option is constructed with a small WTW, and then a second raw water option is constructed with a second small WTW
- Both raw water options are constructed at the same time, with a larger treatment works which can treat the water provided from both resource options
- One raw water option could be built first, along with the larger treatment works; the second raw water option could then be built later with no need to build a larger treatment works

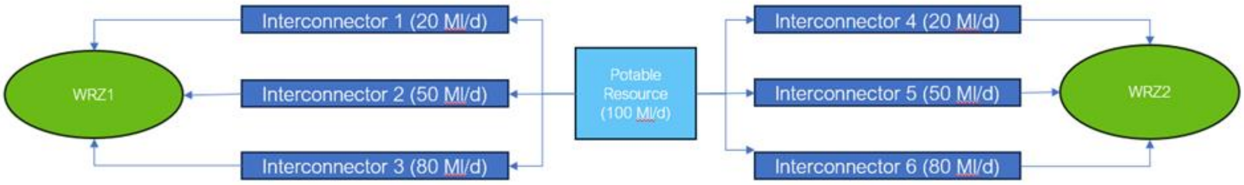
W.126 By considering the raw water options and WTWs as separate option elements, the IVM would be able to identify the optimum solution for the long term.

Example 3 – Phased options



W.127 In this example, a single 100 Ml/d phase of a potable resource option may be cheaper to build than two 50 Ml/d phases. However, according to the need in a given scenario (or according to differing needs in different adaptive branches), building resources in phases may be the optimum approach. It may also be that the second phase of the scheme would be cheaper than the first (for example, if land acquisition is required). In this case, a dependency would be included to note that the "phase 2" option could not be built until the "phase 1" option is built.

Example 4 – Shared resources

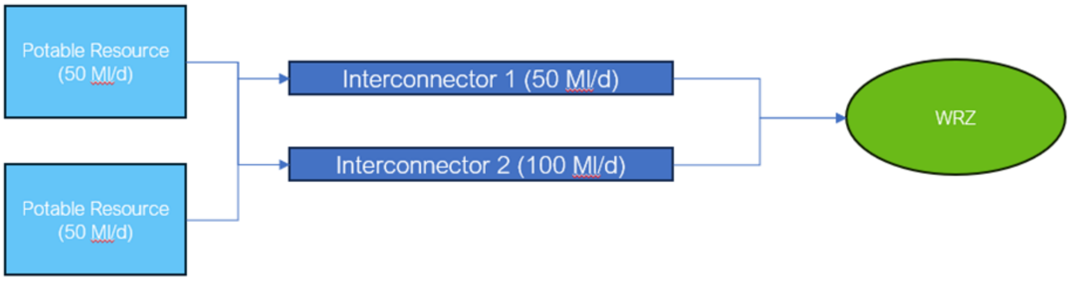


W.128 In this example, a single potable resource option could be used to fulfil needs in one of two resource zones, and different interconnector options may exist to connect the resource to each WRZ. According to the scale and timing of need in each WRZ in different adaptive branches, the potable resource could be shared among the two WRZs in different proportions.

W.129 In this case, having separate "resource" and "interconnector" option elements is required, and they cannot be combined.

W.130 The "potable resource" element would be allocated a resource, but it would be required that an interconnector option connect the resource to either of the WRZs. Each of the interconnector options would be allocated a capacity but would not be allocated a resource.

Example 5 – Interconnectors 1



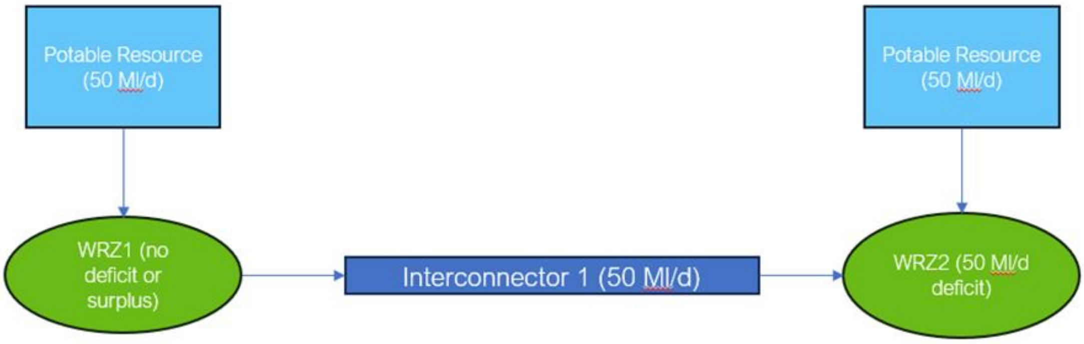
W.131 In this example, two different potable resource options (for example a desalination plant and a direct reuse plant, with the same site used for both) could make use of the same interconnector options, and different sized interconnector options could be developed.

W.132 In this case, depending on the timing and scale of need across different adaptive plan scenarios, it could be that one or both resource options are required. According to the overall scale of need, it may be that the larger or smaller interconnector is needed.

W.133 In this case:

- The potable resource options would be allocated "resource", but it would be required that an interconnector option connect either resource to the WRZ
- The interconnector options would not be allocated "resource", but would be allocated a "capacity"

Example 6 – Interconnectors 2



W.134 In this example, there exists a WRZ with no surplus or deficit and another WRZ with a deficit. There is a potable resource option available to each WRZ, and an interconnector option to transfer water from WRZ1 to WRZ2.

W.135 If it is the case that the potable resource option available to WRZ2 is very expensive, it may be more efficient to build the potable resource option for WRZ1 and the interconnector, rather than the potable resource option for WRZ2.

W.136 In this case:

- The potable resource options would be allocated “resource”, and the resource options would be connected to the relevant WRZ
- The interconnector option would not be allocated “resource”, but would be allocated a “capacity”

Dependencies

W.137 As is described in Section 7 of our WRMP, we have considered the wider system reinforcements which would be necessary should treatment expansion be undertaken in a combination of East and West London. These wider system reinforcement options are included as “dependent” options. In this case, the combinations of treatment options in East and West London are made dependent on the construction of different system options.

Changes made between rdWRMP24 and Final WRMP24

We have included additional information in this section as a result of a request for information made by Defra, including:

- Details of assurance undertaken of the WRSE IVM
- Programme-level vs option level costs
- Illustrative examples related to system complexity in programme appraisal

Thames Water