Thames Water

Final Water Resources Management Plan 2019

Technical Appendices

Appendix W: Programme appraisal methods

Table of contents

Figures

Tables

Appendix W.

Programme appraisal methods

- This appendix is a series of methodology statements which together explain the process by which our preferred plan for the revised draft Water Resources Management Plan 2019 (WRMP19) has been developed and selected. The three documents are as follows:
  - Part A: Problem characterisation for selection of appropriate planning horizon and assessment methods
  - Part B: Programme development and appraisal methods
  - Part C: Metrics for best value programme development and appraisal
- Part A characterises (i.e. defines the extent and complexity of) the planning problem in our water resource zones (WRZ), and identifies appropriate methods for developing potential solutions over an appropriate time horizon. Part B explains the modelling approach (i.e. method) selected from among those appropriate to the level of problem, to develop solutions to the planning problem. Part C explains the metrics (e.g. cost, environmental impact, resilience, deliverability, intergenerational equity, preference and adaptability) developed for use within the modelling in order to identify and evaluate potential best value water resources investment plans.
- The outcome of the problem characterisation underpins and shapes the work described in the subsequent parts of this appendix.

A. Part A: Problem characterisation and planning horizon

Summary

W.1 For Water Resources Management Plan 2014 (WRMP14), we assessed the water resources planning problem over a twenty-five year planning horizon for all six WRZs, using the Economics of Balancing Supply and Demand (EBSD) method.

W.2 However, the latest Water Resources Planning Guidance (WRPG) published in July 2018[1] advocates selecting the method for the WRMP19 planning contingent on the complexity of both the planning problem and options available to solve the problem. The WRPG states that the planning horizon should be extended beyond the statutory minimum of 25 years where there is good reason to do so.

[1] Environment Agency and Natural Resources Wales, Water Resources Planning Guideline: Interim Update July 2018

W.3 The method for characterising problem complexity (as explained in the WRPG) is worked through within this method statement to determine the best type of programme development model for our WRZs. We commissioned NERA (National Economic Research Association) to assess the reasons for which extension of the planning horizon would be beneficial, and this document also evaluates the best planning horizon for each WRZ in light of NERA's review[2].

W.4 The supply-demand problem and potential solutions for London, Swindon and Oxfordshire (SWOX) WRZs are found to be complex and potential solutions controversial; for Slough, Wycombe and Aylesbury (SWA) WRZ the problem is medium, hence enhanced planning methods are recommended for these zones. The planning horizon for all three is also extended to 80 years. Although the planning problem for our remaining three zones is of low complexity they are also assessed over the same horizon to allow inclusion of inter-zonal transfers with London, SWOX or SWA.

Introduction

Problem characterisation

W.5 Problem characterisation is carried out to guide water resource planners toward the appropriate method of assessment for the size and complexity of their planning problem. Analysis of the size and complexity of the planning problem also guides planners to the appropriate length of planning horizon, and therefore both assessment method and planning horizon are outcomes of the problem characterisation assessment within this document.

W.6 UK Water Industry Research (UKWIR) produced *WRMP 2019 Methods – Decision Making Process: Guidance*[3], hereafter referred to as the guidance, to provide 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.

W.7 The guidance also makes clear that while 25 years is the statutory minimum time horizon for water resources planning, there is strong encouragement to take a longer term view where it is appropriate, particularly in view of longer term pressures, uncertainties and the time it takes to develop some infrastructure. A longer horizon should be justified where appropriate. In light of the complex water resource planning problem in the south east and the ongoing pressures associated with population growth and the forecast impacts of climate change, we commissioned NERA to develop a framework for assessing the most appropriate time horizon for water resource planning. NERA were part of the expert team who developed the UKWIR guidance.

[2] NERA, What is the Appropriate Horizon for Integrated Water Resource Planning?, Nov 2016

3 UKWIR, WRMP19 Methods – Decision Making Process: Guidance, Report Ref. No. 16/WR/02/10, 2016

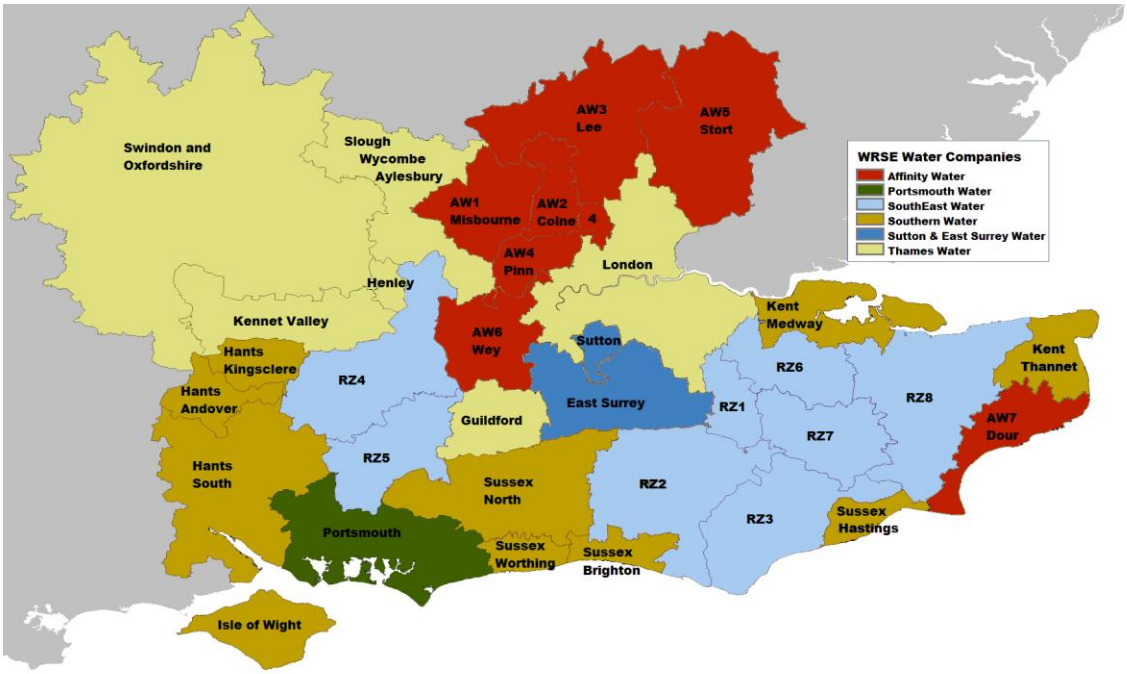
W.8 There are five further sections within this methodology statement:

- Characterising the water resources planning problem for our supply area
- Appropriate time horizon over which to address the planning problem in our supply area
- Appropriate methods to assess our planning problem over the selected time horizon
- Problem characterisation in the wider context of south east England
- Conclusion

Characterising the water resources planning problem for our supply area

W.9 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.

Figure W-1: Water resource zones in south east England



W.10 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 historic, in perpetuity agreements. Most are relatively small and not large enough to affect the integrity of our WRZs. Further transfers are anticipated in the future, see Section 5: Allowing for risk and uncertainty.

W.11 For each WRZ, the guidance requires planners to consider a set of questions that can be used to define the strategic risk in each WRZ, demand complexity, supply complexity and investment complexity. Answers can then be scored and put in a matrix to define an overall high, moderate and low level of concern.

W.12 The scores from the analysis are shown in Table W-1 to Table W-4. The detailed consideration of each question is provided in Annex 1: Problem characterisation worksheet.

Table W-1: Strategic risk

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

Table W-2: Supply complexity

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	2	**8**
SWOX	1	2	1	2	**6**
SWA	0	0	1	1	**2**
Kennet	0	0	0	0	**0**
Guildford	0	1	1	0	**2**
Henley	0	0	0	0	**0**

Table W-3: Demand 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	1	1	1	**3**
SWA	1	1	1	**3**
Kennet	1	1	1	**3**
Guildford	1	1	1	**3**
Henley	1	1	1	**3**

Table W-4: Investment 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	1	2	**7**
SWOX	2	2	1	1	**6**
SWA	2	2	1	1	**6**
Kennet	0	0	0	0	**0**
Guildford	0	0	0	0	**0**
Henley	0	0	0	0	**0**

W.13 The above scores have been combined into the problem characterisation heat map, as advised in the guidance, to give an indication of the complexity per WRZ as presented in Table W-5.

Table W-5: Problem characterisation results by WRZ

Problem characterisation		**Strategic risk score (From Table 1)**			
		0-1	2-3	4-5	6
Complexity factors score (Sum of Tables 2-4)	Low <7	Henley Kennet Valley	Guildford		
	Medium 7-11			**SWA**	
	High (11+)			**SWOX**	**London**

W.14 This analysis demonstrates that the London and SWOX WRZs have a water resource planning problem of high, significant concern. The SWA WRZ has a moderate level of concern, while the remaining WRZs are of low concern.

Appropriate time horizon over which to address the planning problem in our supply area

> *"The time horizon should be chosen so that events beyond the horizon end would be unlikely to affect the decisions about what to do initially" (NERA, 2016).*

W.15 Where there is no relevant deficit, or sufficient robust, low-cost options which can be quickly implemented, then the statutory minimum 25 year planning horizon is sufficient.

W.16 However, where there is a large potential deficit, and options have long lead times and long asset lives, extension of the planning horizon may be necessary to ensure equitable, comparable assessment; this need must be weighed against the decreased reliability of forecasts over a longer time horizon. One of the key limiting factors for extension of planning horizon is the impact of the discount rate on investment in the distant future. NERA state that events beyond horizons of 100 years are most unlikely to influence the initial steps, and therefore a planning horizon beyond this limit is unlikely to be justified.

W.17 In order to assess the correct planning horizon for a complex problem, NERA advocate use of a stepwise approach for extending the 25 year planning horizon in five year timesteps, by a flow chart of questions, which can be translated into a score as shown in Table W-6. A worked example is given for the London WRZ relating to the statutory 25 year planning period and its potential extension to 30 years. A score of zero indicates that the planning horizon should be extended by five years, and the assessment repeated.

Table W-6: Assessing the potential for extending the planning horizon beyond 25 years

Assessment	Yes	No	London 25-yr
Are discounted net costs beyond the proposed horizon substantial?	0	1	0
Are asset lives considerably longer than the proposed horizon?	0	1	0
Are rapid low-cost solutions insufficient for needs within the proposed horizon?	0	1	0
Is there strong concern about events beyond the proposed horizon?	0	1	0
Can reasonable forecasts be generated to extend the proposed horizon?	0	X	0
Score			**0**

W.18 Due to the lack of availability of low-cost options which can be rapidly implemented, the significant cost and asset life of alternative large scale options, and the uncertainty around the impact of impending legislation, climate and population changes for London, a 25 year planning horizon would give a 'yes' answer to all five questions, giving a total score of zero. The zero score indicates that extension of the proposed planning horizon is both feasible and necessary, while a score of four would indicate that the proposed planning horizon is appropriate. The requirement and feasibility of extension is assessed in five year intervals for each zone, iterated until acceptable forecasts can no longer be generated beyond the proposed horizon.

W.19 The scoring for each WRZ is presented in Annex 2, summarised in Table W-7 from 25 to 100 years. The appropriate horizon can be selected from the range showing the highest score for each zone.

Table W-7: Summary of scoring for extending planning horizon assessment

Is the current planning horizon appropriate?																	
Potential planning horizon (years)																	
Water Resource Zone	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	Appropriate horizon
London	0	0	0	0	0	0	0	0	2	2	2	2	X				65-80
SWOX	1	1	1	1	1	1	0	0	2	2	2	2	X				65-80
SWA	1	1	1	1	1	1	0	0	2	2	2	2	X				65-80
Kennet	4	4	4	4	4	4	4	4	4	4	4	4	X				25
Guildford	4	3	3	3	3	3	3	3	3	3	3	3	X				25
Henley	4	4	4	4	4	4	4	4	4	4	4	4	X				25

W.20 The analysis demonstrates that a planning horizon of between 65 and 80 years would be most appropriate for London, SWOX and SWA. Our remaining zones do not necessarily require planning horizon extension beyond 25 years.

W.21 As the baseline supply-demand gap is currently forecast to continue to expand beyond 100 years, the limiting factor on selecting the planning horizon for London, SWOX and SWA is forecast uncertainty. As such it is appropriate to select the longest time horizon within the appropriate range, and an 80 year horizon has been adopted for all three zones. An 80 year planning horizon aligns with that chosen by the Environment Agency when deriving its strategy of flood protection for London. The economic and social consequences of water supply failure in London would be equally as catastrophic as those associated with flood inundation and as such it is appropriate to work to the same planning horizon when deriving the strategy for future water supply.

Appropriate methods and metrics to assess our planning problem over the selected horizon

W.22 The problem characterisation matrix (Table W-5) demonstrates that both London and SWOX WRZs have a problem of high, significant concern and that SWA has a problem of moderate concern. The guidance therefore recommends the use of extended or complex risk-based techniques for thorough analysis of the planning problem, as described in Part B.

W.23 The other WRZs have low complexity problems and analysis of Guildford, Henley and Kennet Valley WRZs can therefore be carried out over a 25 year period using the current EBSD approach where the net present value (NPV) of the investment programme is optimised. However, as the available options to London, SWOX and SWA include transfers from Kennet and Henley, the planning horizon has been extended to 80 years for all zones.

W.24 We have developed a range of scenarios to fully sample the complex planning problem in London, SWOX and SWA, and use both aggregated and system simulation methods to develop potential solutions which are evaluated using a range of performance metrics. The metrics are:

- Cost
- Environmental performance
- Resilience
- Intergenerational Equity
- Adaptability
- Deliverability
- Preference

W.25 These metrics are fully described in Part C of this appendix.

Problem characterisation in the wider context of south east England

W.26 In the context of Water Resources South East (WRSE), our problem characterisation identifies that the London WRZ has a high strategic need and high complexity affecting identification of the best solution. When London is considered in conjunction with neighbouring water company zones, the problem expands beyond the immediate WRZ and company boundaries.

W.27 Existing, in perpetuity, water transfers export water from London to Essex and Suffolk Water (91 Mld in normal years, temporarily reduced to 71 Mld in drought years until April 2035) and Affinity Water (15 Mld). Further new transfers have been proposed and assessed as part of the strategic water resource planning by the WRSE group of six water companies4 (Table W-8).

Table W-8: Resource required by WRSE water companies (revised draft plan or sensitivity testing)

Donor Zone	Type	Mld	Date	Recipient Company	Recipient Zone	Scenario
SWOX	**Raw**	**100**	**2038**	**Affinity Water**	**AW4**	**Revised draft plan**
London	Potable	30	2045	Sutton and East Surrey Water	SUT	Sensitivity testing
Kennet	Potable	10	2045	South East Water	RZ4	Sensitivity testing
SWOX	Raw	20	2065	South East Water	RZ4	Sensitivity testing
SWOX	Raw	50/ 75/ 100/ 125	2027	Southern Water	HAM	Sensitivity testing

W.28 A strategic resource was included in the draft WRMP19 to share capacity between Thames Water, Affinity Water, South East Water, and Sutton and East Surrey Water.

W.29 Immediately prior to submission of Thames Water's draft plan, Sutton and East Surrey Water[5] notified us that they no longer required a strategic transfer of 30 Mld of potable water from London within the current WRSE planning horizon (to 2080).

W.30 Between submission of draft and revised draft plan, South East Water[6] has notified us that the strategic transfers from Kennet and SWOX are no longer required within the current planning horizon due to reduced growth forecasts and increased demand management.

W.31 Southern Water[7] no longer require additional resource to Kent Medway even in their extreme scenarios, but have been in correspondence with Thames Water requesting we assess scenarios where a significant strategic transfer is available to supply their Hampshire zones.

[4] Affinity Water (AW), Portsmouth Water (PW), South East Water (SEW), Southern Water (SWS), Sutton and East Surrey Water (SESW), and Thames Water (TWUL)

[5] Murphy, A. Email correspondence, November 2017

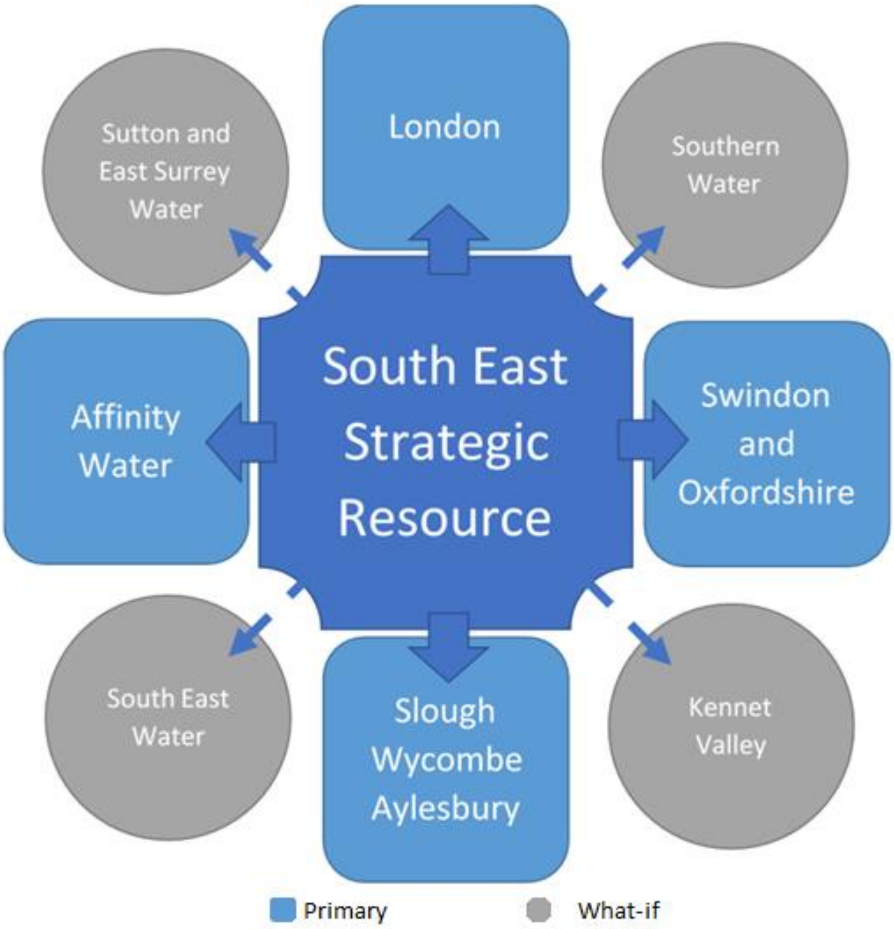
[6] Dance, L. Letter, August 2018

[7] Gough, M. Email correspondence, July 2018

W.32 Need for a strategic resource in the South East would therefore be driven by the joint requirements of Thames Water and Affinity Water[8] for this revised draft plan. However, while sensitivity testing for different potential futures (either Adaptability or What-if scenarios) we have also included the previous or additional potential strategic requirements from other companies in the South East to evaluate the potential to meet broader needs should growth or demand management forecasts alter.

W.33 An additional What-If scenario looks at potential reduction of resource available from the West Berkshire Groundwater Scheme, requiring significant alternative resource in Kennet Valley and London zones, which could only come from a strategic resource.

Figure W-2: Southeast Strategic Resource Option: Primary and What-if scenario demands within the revised draft plan



W.34 Planning methods for connected or potentially connected neighbouring zones should ideally be as closely aligned as possible to best analyse transfer capabilities and shared resource

[8] Walsh, P. Letter, July 2018

planning where a problem is significant and widespread. Affinity Water Zone 4, London, SWOX and SWA may all require additional water from the strategic resource, so the same analysis method should be used in all Thames Water zones, and ongoing communication with Affinity Water has enabled significant alignment of both company analysis methods.

Conclusion

W.35 We have characterised a problem of significant concern and complexity in London and SWOX WRZs and of moderate concern in SWA WRZ.

W.36 For these zones, an 80 year planning horizon has been selected, both using the method advised by NERA to take into account problem continuity, asset life and investment horizons, and by consideration of planning horizons of neighbouring zones and potential water trading partners. The same planning horizon has been extended to Henley, Kennet Valley and Guildford zones to enable assessment of transfers between our WRZs.

W.37 Complex assessment methods have been developed for London, SWOX and SWA WRZs which reflect the significance and complexity of the planning problem. The London WRZ in particular also has been considered in the context of WRSE as investment solutions have potential to contribute to the wider water resources need identified in the South East.

B. Part B: Appraisal methods

Summary

W.38 Our WRMP14 programme appraisal method used least-cost optimisation as the primary driver for the search for the best programme of investment to fill the supply-demand gap. Solutions were then modified in light of other parameters such as environmental and social costs, risk, and resilience. Sensitivity testing against different futures was carried out on the preferred plan.

W.39 The WRPG advocates moving away from strict least cost planning to a more comprehensive evaluation of additional values which cannot be feasibly monetised. More complex methods of system simulation allow better exploration of the effects of the uncertainties embedded within the problem boundaries, together with direct rather than deterministic simulation of the effects of multiple scenarios on values such as yield, cost, system reliability and resilience.

W.40 With multiple potential impacts being considered at once, single-objective optimisation has become impractical as this would either require converting all metrics into one common unit, or assigning a weight to each benefit beforehand. Moreover, the emphasis on stakeholder engagement and transparency has supported the desire to move away from a strictly least-cost selection of plans to a more transparent method, where the impacts of water plan choices on several criteria of importance can be considered explicitly within the selection process.

W.41 As such, we have relied on option selection processes which produce multiple potential investment programmes for simultaneous appraisal of their several diverse metrics using expert judgement.

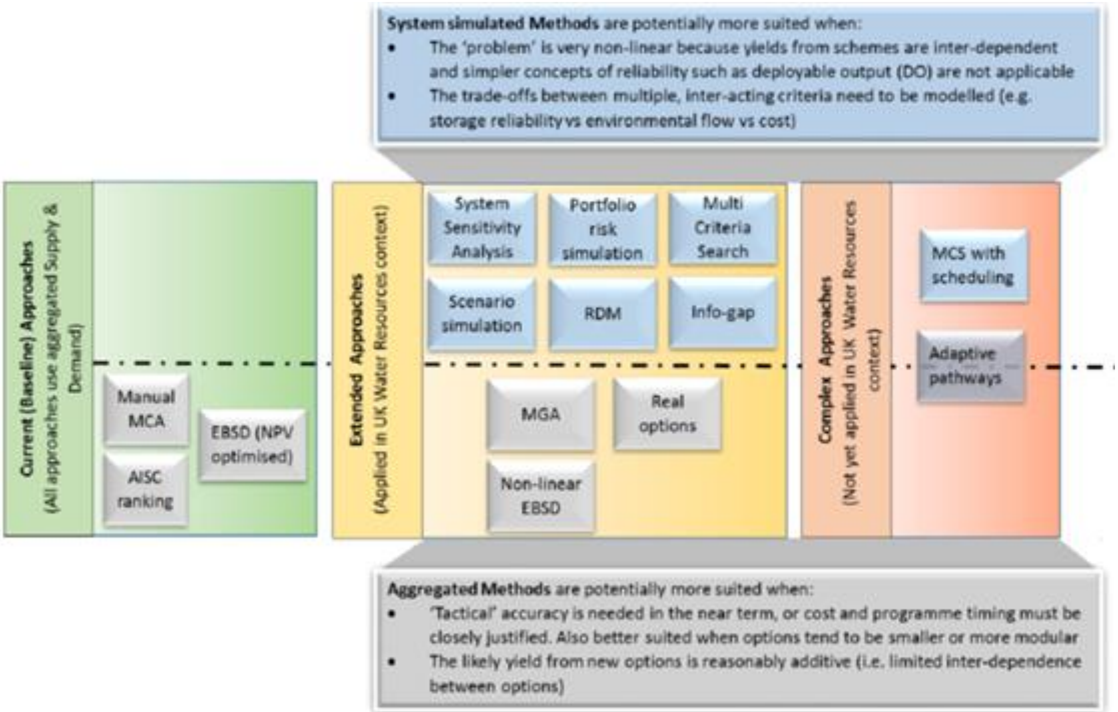
Introduction

Problem characterisation

W.42 In Part A we identified that both London and SWOX WRZs currently have water resource management problems of high, significant concern and complexity; SWA WRZ has moderate concern, and the remaining three zones (Kennet Valley, Guildford and Henley) have planning problems of lesser concern, and can therefore use the established EBSD method for water resource planning for revised draft WRMP19.

W.43 The guidance recommends the use of extended or more complex risk-based techniques than EBSD for thorough analysis of planning problems of moderate or high concern and complexity: see Figure W-3.

Figure W-3: Planning methods for problems of different complexity, Guidelines (UKWIR 2016)



Programme development and appraisal

W.44 The UKWIR 2016 guidance presents advice regarding suitable methods for water companies to develop potential programmes of investment for revised draft WRMP19. This document details the specific types of methodologies selected for development of multiple potential programmes of investment for our planning problem in the London, SWOX and SWA WRZs. The least-cost EBSD method will be used for the remaining zones with low complexity.

W.45 The number and diversity of the programme appraisal metrics makes it unreasonable to weight them for aggregation into a common value for single-objective optimisation in a decision support tool (DST). This has shaped both the search algorithms used for programme development, the depth of expert judgement required within the programme appraisal process, and the design of a further DST for parallel visualisation of multiple metrics amongst the multiple programmes.

W.46 The four remaining sections within this section describe:

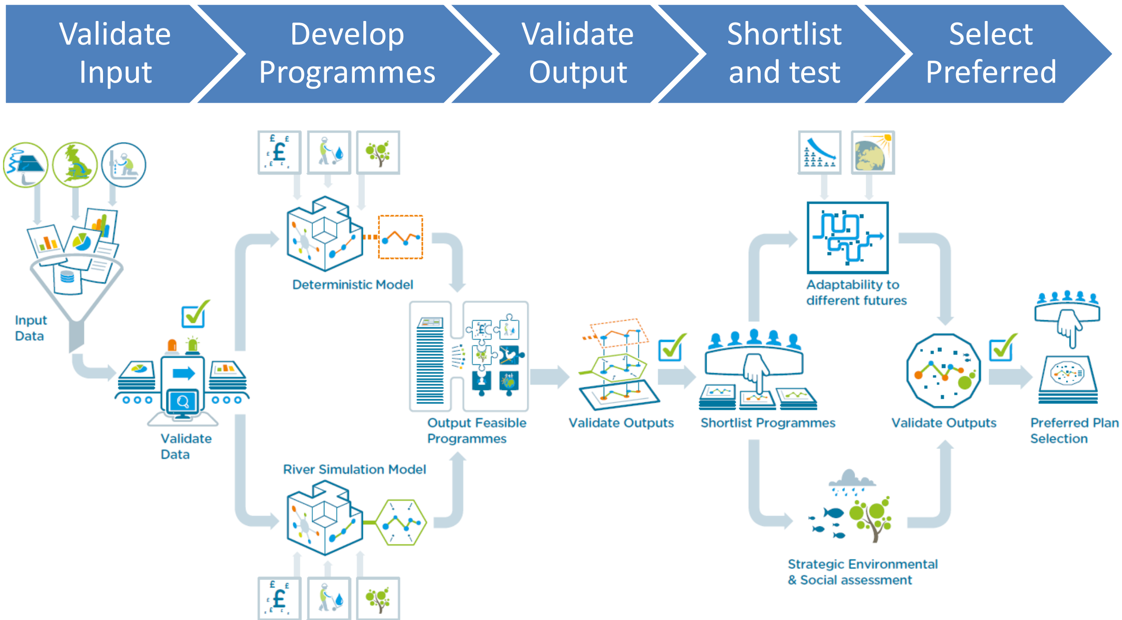
- Revised draft WRMP19 programme appraisal process overview
- Programme development: modelling framework and selection routine
- Visualisation tool for parallel assessment of multiple potential plans
- Conclusions

Revised draft WRMP19 programme appraisal process overview

W.47 Due to the complex nature of the planning problem for London and SWOX and SWA the investment plan for the revised draft WRMP19 includes major strategic options which could be controversial.

W.48 This level of complexity of both problem and solution means that extended and advanced programme development tools have been used to produce multiple feasible solutions of different value, measured by several metrics, from which the preferred plan has been selected and the selection justified. The process by which potential plans are developed and then appraised and further tested to find the best value solution is outlined in Figure W-4.

Figure W-4: Revised draft WRMP19 programme appraisal process



- **Validate input:** Ensure that despite the differences in format for the different models, the input data is from the same source and equivalent for the different models.
- **Develop programmes:** Use the models, described in Part B, to develop multiple potential investment programmes.
- **Validate output:** Consolidate output from different programmes developed by the different methods to assess differences and similarities. Investigate any differences in metric scores to ensure validity. Consolidate identical programmes produced by both where applicable.
- **Shortlist and test:** Use the visualisation tool (Part B) to assess all available programmes and shortlist ten to twenty for further testing. Internal assessment is carried out first, and our selection passed to an external expert panel for critique and challenge. The Adaptability and Environmental Impact at a plan-level is assessed for shortlisted programmes.
- **Select preferred:** The preferred plan will be selected from the shortlisted programmes, including the additional data, using the visualisation tool and sharing information between experts as per Section 10: Programme appraisal and scenario testing.

Programme development

W.49 Any method of water resources programme development combines a way of evaluating programme performance with a search for the best-performing programme. We have developed the following methods:

- **EBSD** combines cost analysis with single objective least cost optimisation
- **EBSD+** combines analysis of multiple parameters including cost, with single objective optimisation for each successive parameter. A second search (search within constrained space (SCS)) uses a dual-objective search to find the best solution for each metric within a threshold increase of cost from the least cost solution. The third search finds near-optimal solutions for each parameter in relation to the SCS results, an approach which is known as modelling to generate alternatives (MGA).
- **IRAS_MCS** combines Interactive River-Aquifer Simulation (IRAS) system simulation modelling with multi-criteria search (MCS) to assess and optimise against multiple metrics of performance.

W.50 Each method is described in the sections below.

EBSD

W.51 The EBSD method is well established within the water industry as a means to develop a least-cost programme of investment to maintain supply over a minimum 25 year planning horizon.

W.52 For WRMP14, yearly forecasts of supply were determined by our Aquator simulation model, Water Resources Management System (WARMS), and yearly demand by the demand forecasting model for three defined scenarios of:

- Dry Year Critical Period (DYCP),
- Dry Year Annual Average (DYAA), and
- Normal Year Annual Average (NYAA).

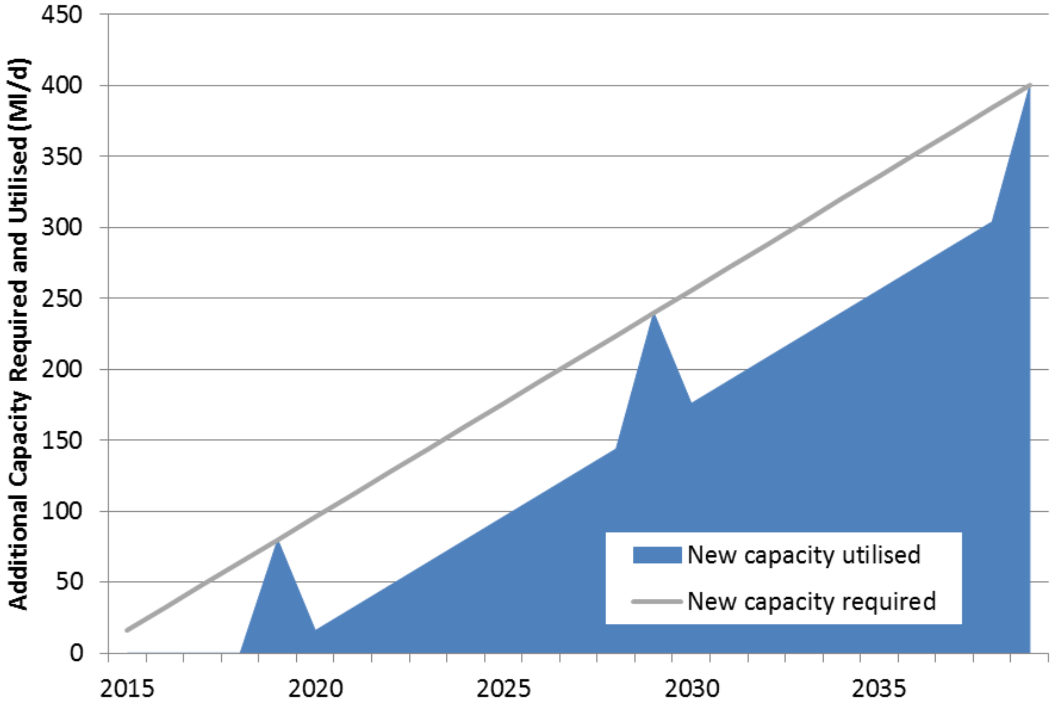
W.53 A target headroom allowance is also determined for each scenario which represents supply and demand side forecast uncertainties across the planning horizon. An additional allowance is added for system outage.

W.54 For each year, the supply-demand gap is the difference between the demand plus target headroom and supply, i.e. the maximum additional capacity required to solve any deficit across the planning horizon to an acceptable level of risk. Sufficient investment options to increase supply or reduce demand are developed which could resolve the deficit. Because several competing options are available, EBSD was used to search for the optimal least cost programme of investment.

EBSD cost calculation

W.55 The EBSD model selects options to satisfy any deficit for each year of the planning horizon and calculates the cost of building and running those options. While the dry year critical peak forecast determines the total capacity required for each year[9], the DYAA and NYAA forecasts are also required to define the proportion of that capacity utilised within each year. Within EBSD modelling, utilisation is calculated to supply normal year demand plus target headroom nine years out of ten, while dry year demand occurs once in every ten years (Figure W-5).

Figure W-5: Example linear approximation of new capacity required and utilised



W.56 EBSD schedules different portfolios of investment using the options available to satisfy any deficit and calculates the annual cost of capital investment and fixed operational costs of all new options, and operational cost of production for the additional capacity utilised. New options are utilised in ranked ascending order of cost, and the ranking revised each time an additional option is commissioned throughout the planning horizon. Annual costs are indexed to the same base year, discounted using the Treasury declining discount rate (Table W-24), and summed to give the NPV of the total programme.

Single objective optimisation

W.57 EBSD programme development and cost analysis is coupled with mixed integer linear programming (MILP) to search for the least-cost schedule of option investment (programme) which will satisfy any deficit (Figure W-6). MILP is also used in EBSD+ to search for the optimal programme in terms of each of the other metrics.

[9] DYCP is the scenario which puts most risk on security of supply in the Thames Valley. There is no DYCP forecast for London (Section 3, paragraph 3.49) and therefore DYAA is used to determine capacity requirement.

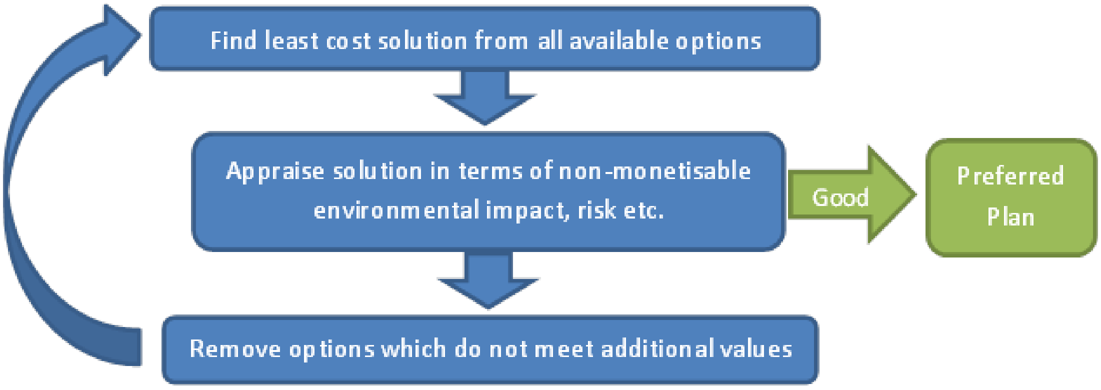
W.58 MILP requires some or all of the decision variables to be constrained as integers, so restricting the search space and enabling solutions close to optimal to be found. Requiring the NPV cost of programmes being optimised to be expressed as integers does not introduce a significant level of error into an analysis, where the total cost is millions if not billions, and the intervals are linear, so MILP is well suited to least-cost optimisation.

W.59 However, not all of the metrics under development were equally suited to linear quantification and assumptions have been made to enable such quantification, which must be taken into account when making judgements based on each metric. The quantification of each metric for optimisation is expressed in the Part C below.

Moving beyond least-cost optimisation

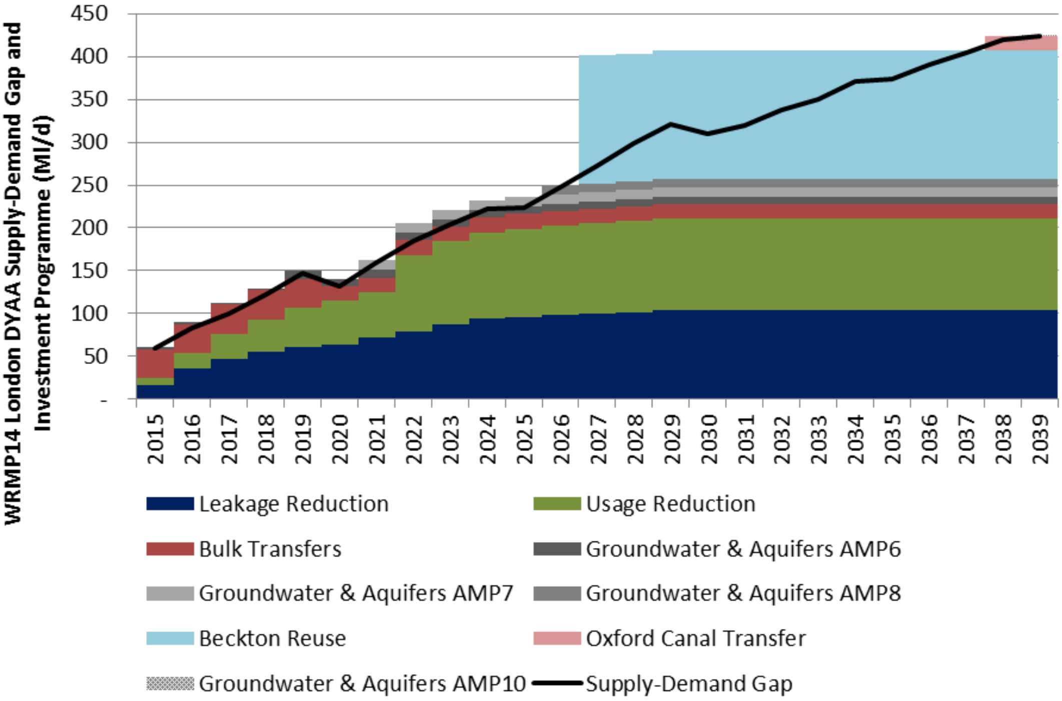
W.60 The least cost solution developed by EBSD for WRMP14 was examined by experts to determine whether for any reason the programme of options presented was not the best in terms of combination of environmental impacts, customer preference, etc. (Figure W-6).

Figure W-6: EBSD programme development and appraisal iterative loop for WRMP14



W.61 Individual options were removed from the pool of those available for these reasons, and the least-cost optimisation repeated until an acceptable programme was identified (Figure W-7). This was presented for consultation as the preferred plan.

Figure W-7: WRMP14 programme of investment for London developed by EBSD



W.62 However, this type of stepwise least-cost search covers only a small number of all potential solutions, always following the least-cost curve for a reducing search space, where a near-least cost solution may provide substantial additional benefit in terms of other metrics. There is also a lack of transparency and stakeholder involvement at the critical stage of programme selection.

W.63 The EBSD model has been expanded for WRMP19, to EBSD+, to enable additional programme assessment and optimisation using multiple metrics in London, SWOX and SWA, described in Table W-9 while the least cost EBSD model has been used for water resource management planning for the low concern WRZs (Kennet Valley, Guildford and Henley), and to determine the least cost programmes for London, SWOX and SWA for comparison with other optimisations.

EBSD+

Multiple parameter evaluation

W.64 EBSD+ seeks to resolve the supply-demand gap with iterative minimisation of all development metrics described in Part C. Each solution provides a single programme, for which the value of each development metric is calculated. Selected programmes are then stress-tested to determine their Adaptability to a range of different futures as described from W.104 below.

Table W-9: Developmental and stress-testing metrics

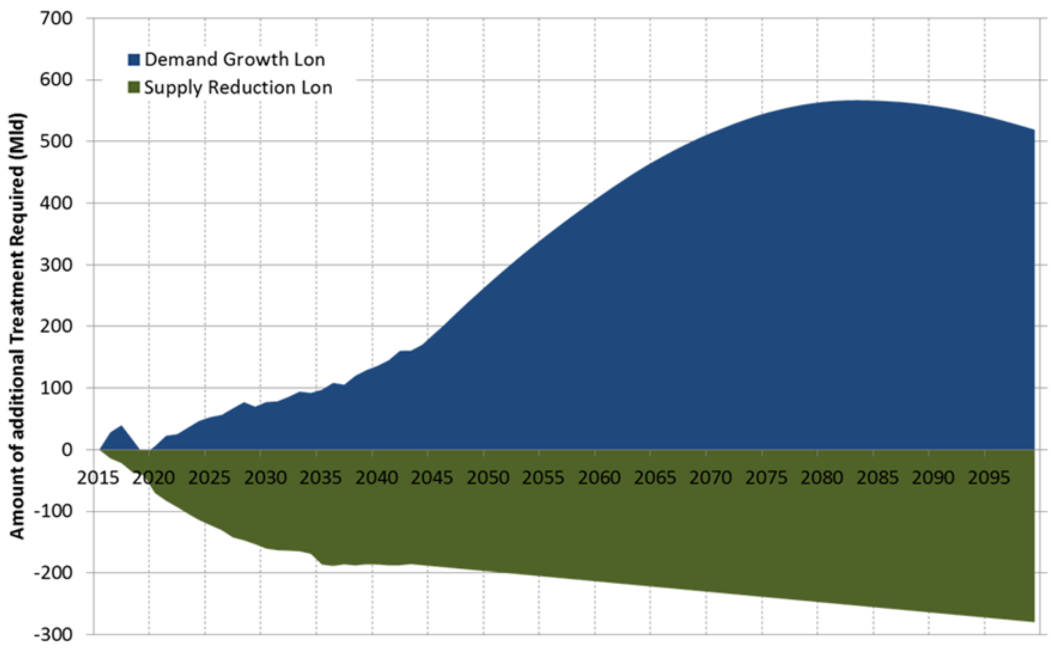
Development Metrics	Stress-Testing
1. Cost	Adaptability

Development Metrics	Stress-Testing
2. Deliverability	
3. Environmental adverse effect	
4. Environmental benefit	
5. Resilience	
6. Intergenerational Equity	
7. Preference	

W.65 Each programme is a scheduled portfolio of options and option elements selected from available resource and demand options (Section 7: Appraisal of resource options and Section 8: Appraisal of demand options).

W.66 EBSD+ optimises using only the resource and conveyance elements of phased options as the selection of raw water system, treatment and network elements is dependent on the capacity of new demand only. Since EBSD+ solves for the entire supply-demand gap based on both reduction to supply (which would not require increased downstream capacity for treatment or network) and increase in demand, it would select more downstream capacity than is needed (Figure W-8) if these were included.

Figure W-8: London DYAA supply-demand gap split between supply and demand



W.67 Moreover, reduction in demand is available within EBSD+ through selection of a demand management programme. This in turn impacts the amount of downstream capacity required, and EBSD+ is not currently designed to carry out an iterative optimisation first for upstream and then downstream elements. The downstream elements are therefore added to selected programmes for SEA analysis as post-processing after optimisation, with capacity dependent on the net increase in demand growth, and location of the selected resource and conveyance elements in each programme.

W.68 Customer Preference optimisation is carried out separately both for Type Preference (Preference for Type of Option) and Frequency Preference (Preference for Frequency, or infrequency, of restrictions). Both metric components and their combination into a single value for any programme are described in Part C. However, optimisation of the two combined stressed the computational feasibility of the optimisation and so they were separated. Initially, therefore, single objective optimisation is used to find an optimal solution for each of these eight parameters.

Search within Constrained Space (SCS)

W.69 Following the initial optimisation for each, a second search is carried out to identify one or several optimal programmes for any metric (excluding cost) within user-defined thresholds that limit the cost increase in relation to the least cost optimisation. A threshold of 120% of least cost has been used for programme development for each of the seven additional development metrics.

Modelling to generate alternatives (MGA)

W.70 Following the SCS search, a third technique called MGA is used to generate solutions which are near optimal, that is, close in value to the SCS solution for each of the seven parameters. By design, MGA finds solutions which are also good with respect to the modelled objective, and yet also are significantly different from each other.

W.71 The user can select how many SCS and MGA optimisations are required for each parameter. For the revised draft EBSD+ has generated up to 36 comparable investment programmes of good value for each of a variety of scenarios[10] (Table W-10), which are then evaluated in programme appraisal.

Table W-10: Optimisation batch for each scenario within EBSD for draft planning

Search	COST	ENV+	ENV-	DELV	RESI	IGEQ	PREF(T)	PREF(F)
Optimal	1	1	1	1	1	1	1	1
SCS		2	2	2	2	2	2	2
MGA		2	2	2	2	2	2	2

[10] Key scenarios include the baseline supply demand balance for a zone, additional resilience to a 200 year drought, and additional regional transfer requirements.

Further testing

Simulation-based portfolio development

W.72 While aggregate models such as EBSD solve the water resource planning problem based on the pre-determined most likely forecasts for supply and demand, simulation modelling directly models the effect of external influences on supply or demand, most commonly different weather patterns that can be used to assess, for example, the potential supply available under a wide range of different future river and groundwater levels influenced by weather variation and climate change uncertainty.

W.73 We have several system simulation models which use weather as a boundary condition:

- the Aquator model (WARMS2[11]) which is used for detailed DO analysis and forecasting
- an IRAS model for strategic river simulation modelling
- a climate and leakage management model (CaLM) which predicts leakage variation under different weather patterns
- a demand model which predicts usage variation under different weather patterns (Domestic Water Use Study model)

W.74 In order to be effectively used for WRMP portfolio[12] development or scheduling, a simulation model must have a sufficiently rapid runtime that when called multiple times by an optimisation search engine the search is not onerous in terms of time. Our IRAS model was developed for this reason, as the WARMS2 model is too detailed for rapid optimisation modelling[13].

W.75 The inputs to IRAS include the water resource system network organization, resource options, operating rules etc, and a time series of stochastically-generated weather data which allows the model to investigate the effects of multiple future weather conditions which may occur, perturbed by climate change forecasts.

W.76 Demand is another key input to the model, modelled from population and property forecasts developed from the Local Authority projections. Population modelling is a complex problem currently outside the scope of water resource planning simulation, although variation from the most likely trend can cause significant variation in demand in areas of high population density, and therefore should be included for full analysis. The effect of population variation is assessed as part of investment programme stress testing in adaptability analysis.

W.77 IRAS is used with two different tiers of optimisation search:

- Portfolio_MCS, where the multi-criteria search (MCS) algorithm finds a range of good value portfolios of options that can satisfy final year demand across a wide range of weather scenarios for that year
- Scheduling_MCS, where the search algorithm finds the best schedule of investment for a selected portfolio to satisfy the full demand profile under a wide range of weather patterns that span the planning horizon.

[11] An update to WARMS completed in 2017

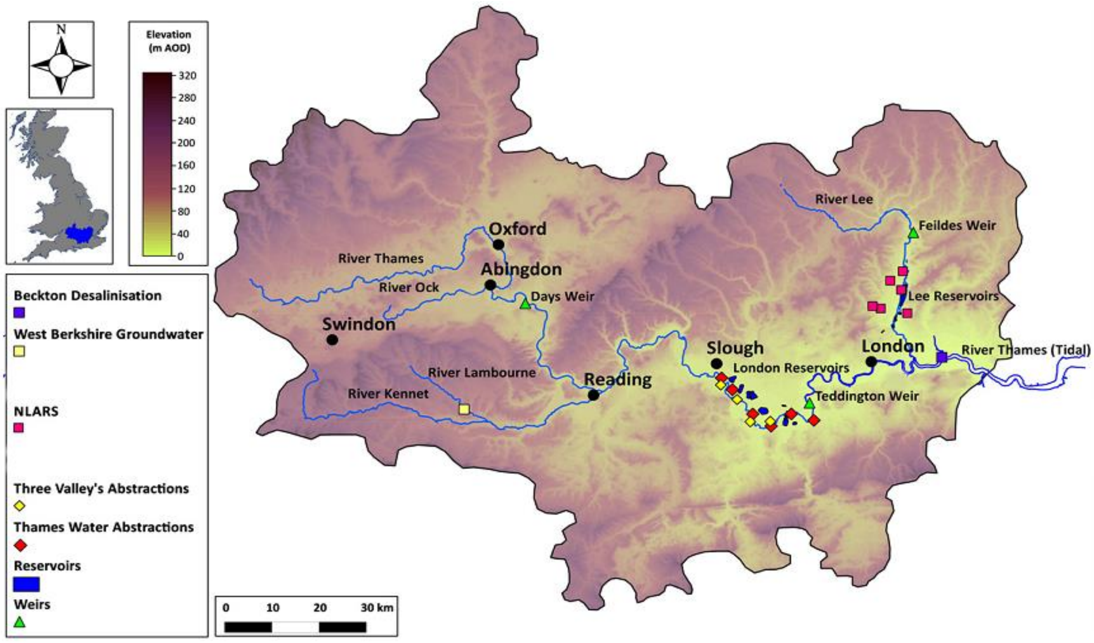
[12] EBSD+ develops **programmes** of investment options to satisfy any deficit across the 80-year planning horizon. IRAS_MCS develops **portfolios** of investment options that will satisfy any supply-demand deficit across the final year of the planning horizon, for multiple supply scenarios simulated from weather ranging from wet to drought. The options selected in IRAS **portfolios** are later scheduled across the planning horizon to form IRAS **programmes**.

[13] Use of cloud computing for optimisation using Aquator models is being investigated for WRMP24

Our simulation model [IRAS]

W.78 The primary source of water for the SWOX, SWA and London WRZs is the River Thames, and a strategic simulation model for the Thames and Severn catchments has been developed to enable evaluation of the effects of large new resource options which would augment flow in the Thames in SWOX (Abingdon reservoir or supported Severn-Thames transfer) and hence increase downstream abstraction for all zones, in conjunction with analysis of potential increase of reuse/ desalination in London. The model can also evaluate increased abstraction for intermediate South East Water or Affinity Water zones along the river between SWOX and London.

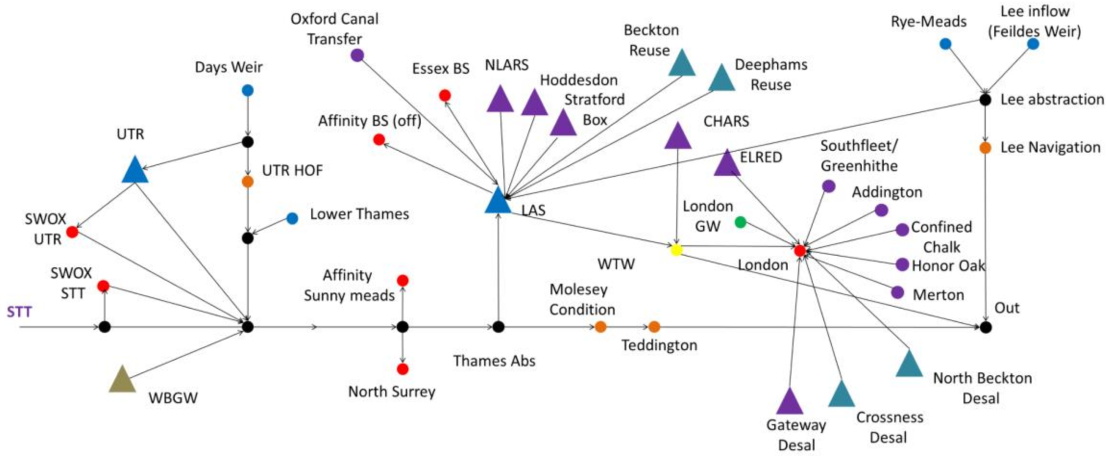
Figure W-9: Example IRAS map view of the Thames basin



W.79 Within the Thames catchment, surface water accounts for roughly 65% of water supplies and groundwater 35%, abstracted primarily by two private water companies: Thames Water and Affinity Water. There are thirteen reservoirs in north-east London supplied by the River Lee (Lee Valley Reservoir Chain) and a group in south-west London supplied by the Thames (Thames Valley Reservoirs). Groundwater comes from boreholes distributed throughout the basin, in addition to the North London Artificial Recharge Scheme (NLARS), where surplus treated water is pumped back into the ground for use during dry periods. In addition to the surface reservoirs and NLARS, the West Berkshire Groundwater scheme (WBGW) in the west of the catchment is available for use during severe droughts (Figure W-9).

W.80 IRAS software is a computationally efficient open-source water resource management simulation computer programme. Our IRAS model tracks system flows, abstractions, consumption, storage and multiple metrics of performance in weekly time-steps across any input time series within the Thames and Severn catchments. IRAS representation of the Thames catchment is in Figure W-10.

Figure W-10: IRAS representation of Thames catchment



- *Inflows into the system*

  Surface water enters the system at Days Weir and Lower Thames on the River Thames and Feildes Weir on the River Lee (Figure W-10). The baseline inflows are denaturalised (i.e. such that all other abstractions upstream from gauges apart from our own are subtracted from the naturalized flows). London's groundwater is modelled as an aggregate inflow directly into London. Rye Meads effluent return enters the River Lee. A new inflow could be supplied via the Severn-Thames Transfer (STT).

- *Water Consumption Nodes*

  These nodes represent WRZ demands, both of Thames Water zones and neighbouring companies. For Portfolio_MCS, demands vary on a monthly basis to simulate seasonal demand variations and give averages and peaks corresponding to 2099/2100. Total demand for each node includes demand-side target headroom and outage allowance.

  When scheduling portfolios, IRAS uplifts the monthly demand profiles by the increase in average demand for each year of the planning horizon.

  The bulk supplies and SWOX and London demand nodes can be supplied from the new inflow via the STT, a new surface storage reservoir (UTR) or existing London storage (LAS). Sunnymeads and North Surrey abstract directly from the Thames, and London is supplemented by groundwater inflow and other new options.

- *Hands-Off Flow (HoF) Gauges*

  UTR HoF, Molesey Condition, Teddington and Lee Navigation are all gauges on the rivers simulated to ensure minimum flow is maintained for the environment and shipping, or to report river levels where drought conditions make this impossible.

- *Storage Nodes*

  LAS is the aggregate existing storage of the Thames and Lee River reservoirs, and UTR is a potential future reservoir at Abingdon. Water is diverted to LAS first from the River Lee and then from the Thames subject to environmental minimum flows directly downstream of the abstractions and maximum daily abstraction limitations.

The WBGW is modelled as a reservoir even though it is a groundwater node. This is the case in both Aquator and IRAS-2010 because it functions like a storage node, with release into the Thames activated by reservoir balance tables which link it to the real-time storage in the aggregate storage node. The WBGW has a set storage level which limits how much it can contribute to the Thames in drought situations. It is refilled by a continuous daily inflow small enough that it cannot serve as an unlimited source. This inflow is lost from the system when the WBGW is not in use.

- *Additional Existing Resource Nodes*

  NLARS, Hoddesdon, Stratford Box, Chingford Artificial Recharge Scheme (CHARS), East London Resource Development (ELRED) and Gateway Desalination are all existing supply option nodes.

- *New London Option Nodes*

  Beckton Reuse, Deephams Reuse, Crossness Desalination and North Beckton Desalination are all new resource options which can be selected and utilised by the model for London WRZ only.

Developing Portfolio_MCS Weather Scenarios

W.81 Three climate change scenarios, id508, id4402 and id9613, were selected from UKCP09 that match the underlying yield-based trend identified from the WRMP14 outputs. HR Wallingford and Atkins then developed 201 stochastic weather traces from each scenario and converted them into a set of 603 stochastic flow scenarios.

W.82 The performance of each flow scenario was analysed using IRAS, to allow ranking by Level 3 reliability (Table W-11). In order to reduce computational burden, 153 scenarios were taken from the ranked set of 603 at even intervals (so ranging from mild to dry and avoiding the introduction of bias), to enable IRAS simulation of these in conjunction with the final year demand profile. These were used to identify portfolios that perform well over a wide range of possible futures (i.e. robust to hydrological uncertainty).

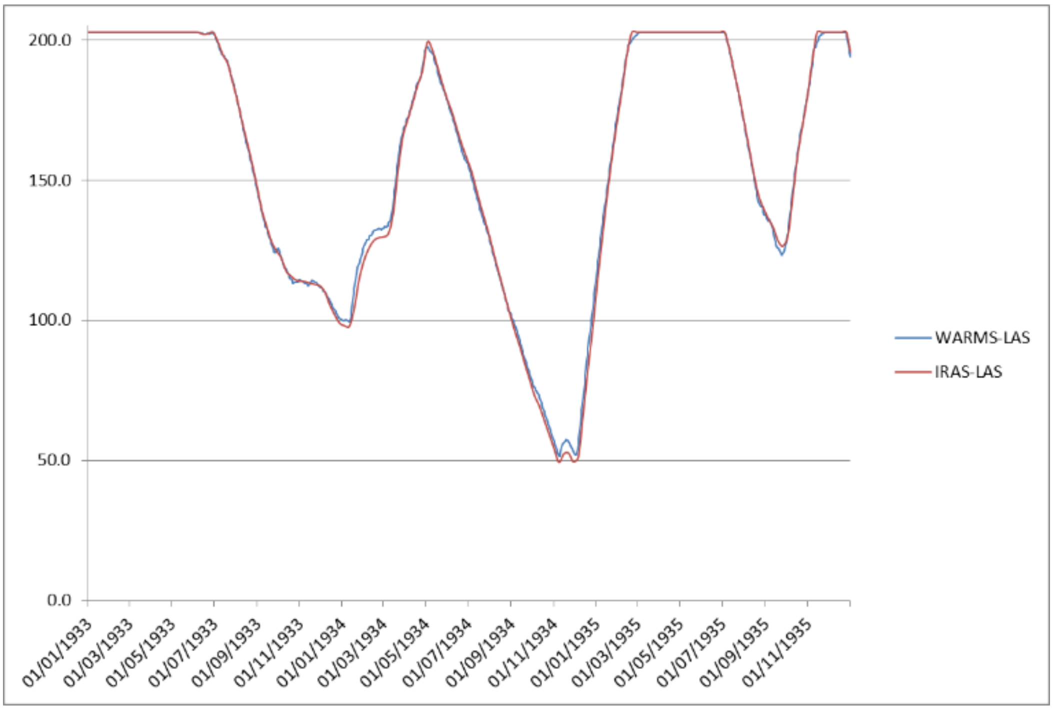
Validating IRAS outputs

W.83 IRAS was calibrated by running the Annual Return 2016 WARMS2-generated flows through the model and checking the aggregated storage against the historic record. The IRAS model was able to produce a good correlation during the critical 20th century droughts, related to WARMS2 flows. Figure W-11 shows the 1933/34 drought, although performance tests were also carried out for the 1921/22, 1944/45 and 1975 severe droughts, with similar results.

W.84 For validation during more severe drought, rainfall and PET for 40 droughts from the stochastic drought library were identified and run through WARMS2 and Catchmod.

W.85 The weather patterns for the 10 years surrounding the critical drought year were extracted from the weather generator. Ten different 10-year drought sequences were then joined in series, together with a 10-year warm-up period, to form a 110-year weather sequence containing ten different droughts. Four of these sequences were created for input to WARMS2, to enable production of calculated yield for 40 different stochastic droughts, for comparison against IRAS[14].

Figure W-11: London Aggregated Storage outputs of IRAS compared with WARMS2



W.86 One discrepancy noted is that IRAS predicts notable differences in DO than WARMS2 for the same 1:200 return period droughts, due to the difference in Catchmod and WARMS2 flows generated[15]. Hence the Level 3 and 4 reliability and resilience metrics and constraints may show different performance than they would in WARMS2. This could result in IRAS recommending portfolios with greater supply (or greater demand management) and could result in options being scheduled earlier with corresponding higher costs, or late, depending on the nature of the drought sampled for scheduling.

W.87 In view of the 1:200 return period drought being the key resilience constraint for rdWRMP19 programme development and selection, IRAS has not been used as the primary tool for these purposes but instead is used to performance test portfolios which most closely match the Reasonable Alternative Programmes (RAPs) and so evaluate their performance against a wide range of weather conditions beyond 1:200 drought, for which the overall correlation is much higher.

W.88 In order to bring simulation modelling into the forefront of programme development and selection for future water resource planning, the calibration of the simulation model to key

[14] Atkins 2018; Thames Water Stochastic Resource Modelling Stage 2&3 Report, Atkins DG04, 16 July 2018

[15] Appendix I, paragraph I.143

drought return periods for scheduling will be improved for WRMP24, potentially by using drought libraries such as described in Appendix I.

Developing IRAS_MCS portfolios

W.89 The multi-criteria search algorithm simultaneously generates multiple portfolios of options which can satisfy 153 different river flow conditions and related aquifer and reservoir storage levels for the London, SWOX, SWA, Affinity and South East Water demands over a 78-year planning horizon. The Portfolio_MCS run for rdWRMP19 produced 66 different solutions for assessment by expert judgement. For each portfolio the simulator has assessed and output several performance measures including average annual cost, environmental impacts and potential level of service failures (Table W-11).

Table W-11: IRAS performance measures

Metric	Preference	Description
Totex	Minimize	Average annual capital + fixed operating + variable operating cost Capex = average annual capital investment over 80 years (£/year) Fixed opex = annual fixed opex (£/year) Variable opex = average annual operating cost (£/Ml*Ml/year) Embedded and operational carbon costs (£/y £/Ml*Ml/year)
Environmental Benefit	Maximize	Sum of benefit scores for all options within a portfolio
Environmental Adverse	Minimize	Sum of dis-benefit scores for all options within a portfolio
Level 3 Recovery Time	Minimize the duration of failures	Average maximum duration of non-essential use failure (LAS storage dropping below the LTCD[16] Level 3 non-essential use) over 153 scenarios * 78 simulated years[17] (weeks)
Level 4 Recovery Time	Minimize the duration of failures	Average maximum duration of emergency failure (LAS storage dropping below the LTCD Level 4) over 153 scenarios * 78 simulated years (weeks)
Level 3 Reliability	Maximize the frequency of non-failures	Average frequency of non-essential use non-failure (LAS storage not dropping below the LTCD Level 3 non-essential use) over 153 scenarios * 78 simulated years (%)
Level 4 Reliability	Maximize the frequency of non-failures	Average frequency of Level 4 non-failure (LAS storage not dropping below the LTCD Level 4) over 153 scenarios * 78 simulated years (%)
SWOX supply	Maximize	Average annual supply to SWOX from Abingdon and STT (Mld)

[16] Lower Thames Control Diagram (Appendix I: Deployable output, Figure I-5)

[17] For Portfolio_MCS analysis, the 78 simulated years is the final year demand profile repeated 78 times against stochastic flow scenarios that have been lined up into a 78-year sequence

Metric	Preference	Description
WRSE supply	Maximize	Average supply to WRSE region (Mld)

W.90 In IRAS more detailed analysis is applied to system resilience than in EBSD+, with analysis of four different components because the model can simulate the frequency and duration of specific level of service risks at a one-week time-step (Table W-12). These map to the revised draft WRMP19 Programme Appraisal Metrics as shown in Table W-12.

Table W-12: IRAS search criteria mapped to revised draft WRMP19 programme appraisal metrics

IRAS search criteria		Appraisal metrics
Totex	→	Cost
Environmental Benefit	→	Environmental Benefit
Environmental Disbenefit	→	Environmental Disbenefit
Recovery Time	→	Resilience
Reliability	→	
Level 4 Reliability	→	

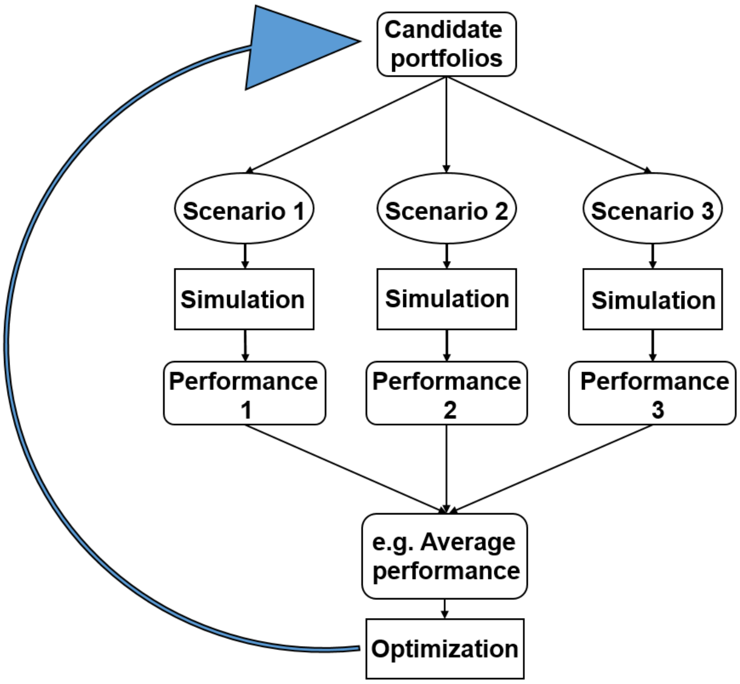
W.91 IRAS is also particularly relevant where multi-system storage or cross-catchment transfers are under analysis, such as when considering a Severn-Thames Transfer (STT) for multiple future flow scenarios; the River Thames and River Severn catchment model are coupled for the full IRAS analysis (see Annex 3 for extension of the IRAS representation in Figure W-10 to include the Severn catchment).

Multi-criteria search (MCS) for portfolio development

W.92 MCS calls the IRAS simulator to assess the performance of many plausible combinations of interventions while searching for robust optimal portfolios. The performance is assessed against eight criteria across 153 x 78-year stationary[18] future hydrological flow scenarios at a weekly time-step.

[18] Meaning the climate change perturbation to the weather remains stationary at the 2099/2100 level for all years.

Figure W-12: Robust multi-criteria search (MCS) approach[19]



W.93 The MCS algorithm generates a pool of potential solutions (candidate portfolios of investment) which the system simulator tests to evaluate the parameters of value across all scenarios (Figure W-12). Within the optimisation, good value solutions (in terms of the trade-offs between all parameters) are identified and the options which make up good solutions are cross-combined or altered slightly to generate a new batch of potential solutions for testing with the simulator (Figure W-13). Each new batch also includes a few unrelated potential solutions to test whether the algorithm is narrowing the hunt in the best area. The process is repeated until the improvement in value of the newest batch is deemed insignificant.

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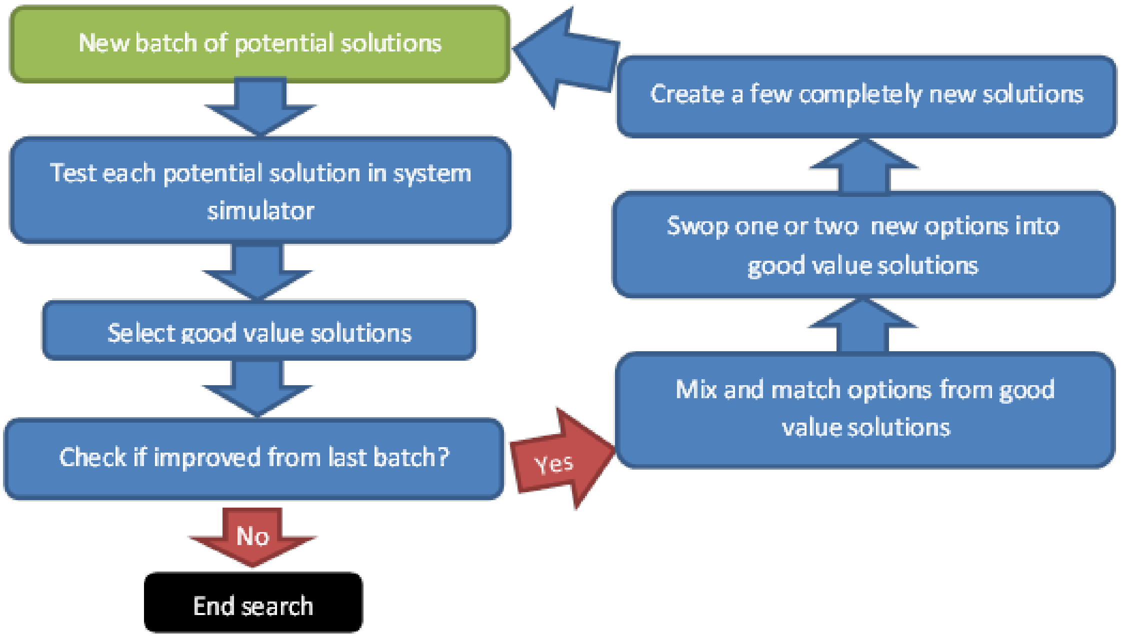
[19] Huskova, I, Matrosov, E, Harou, J, Kasprzyk, J, Lambert, C. (2016) *Screening robust water infrastructure investments and trade-offs under global change: A London example*. Global Environmental Change, 41, 216-227, Nov.

Figure W-13: Process for optimising candidate portfolios



W.94 Both the portfolio and scheduling MCS were performed by connecting the IRAS model to the Epsilon Non-dominated Sorting Genetic Algorithm II, ε-NSGAII (Kollat and Reed, 2006). The parameters in Table W-13 were used.

Table W-13: MCS genetic algorithm parameters

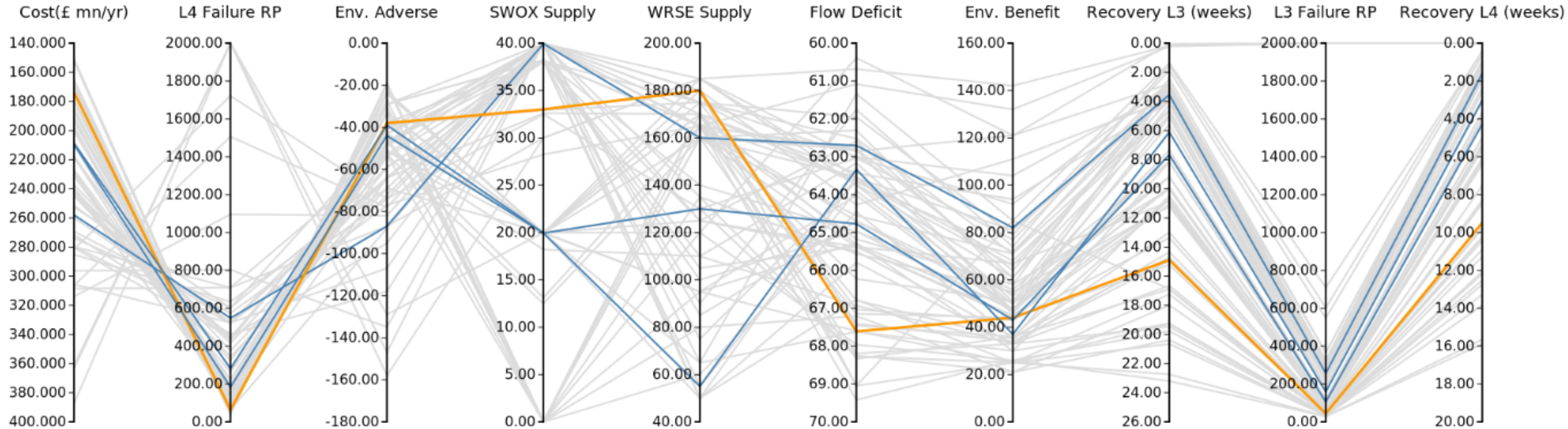
Parameter	Value
Number of objectives	8 (Portfolio MCS) 10 (Scheduling MCS)
Number of decision variables	18 (Portfolio MCS) 24 (Scheduling MCS)
Number of constraints	2
Initial population	128-256
Minimum population	128-256 (depending on No. of cores used)
Maximum population	9996
Number of function evaluations	25,000
Population scaling factor	0.25
Probability of crossover	100%
Probability of mutation	6%
Distribution index for SBX crossover	15
Distribution index for polynomial mutation	20

W.95 All good solutions are exported as robust, valuable portfolios. The rdWRMP19 Portfolio_MCS run produced 66 good value portfolios for consideration for selection and scheduling.

IRAS Portfolio selection for scheduling

W.96 The 66 good value portfolios developed in rdWRMP19 were scrutinised in terms of cost, resilience, and the merits of the options included in each, appraised against defined performance metrics (as shown in Figure W-14 and explained in Section 10-F). The selection of the portfolios for scheduling and further analysis is determined by expert judgement.

Figure W-14: Portfolios selected in PolyVis



W.97 The portfolio ID14654 shown in orange in Figure W-14 was selected as closest to the preferred programme identified from EBSD+, although 100Mld of desalination is available in the portfolio, replacing Deephams reuse and smaller options in the EBSD+ programme. Three additional portfolios were selected by similarity to 14654 in components.

Table W-14: Summary of selected IRAS portfolios

PortfolioID	14636	14665	14655	14654
Reservoir	2 zone 150Mm^3	2 zone 150Mm^3	2 zone 150 Mm^3	2 zone 150Mm^3
STT	2 zone 400MLD	-	Lon only 400MLD	2 zone 400MLD
IPR	3*100 MLD	150 MLD	100 MLD	
Desal	-	2*150 MLD	150 MLD	100 MLD
GW	21.8 MLD	-	-	
Oxford Canal	15 MLD	-	15 MLD	15 MLD
Total Capacity	1,036.8 MLD	615 MLD	965 MLD	815 MLD
Cost	£258m/year	£208.6m/year	£209.4m/year	£173.7m/year
L4 return period	548	280	183	63
SWOX supply	40	20	20	33
WRSE supply	160	55	130	180
Env. Adverse	-87	-39	-44	-38

W.98 Portfolio 14654 has an IRAS Level 4 return period of 63 years, which may reflect requirement for further calibration of the model to 1:200 droughts as the total capacity available is greater than for selected portfolio 14665, which has a Level 4 return period of 280 years. The main difference between the two portfolios is that portfolio 14654 includes the STT but in portfolio 14665 (with the higher return period) this has been replaced by further reuse and desalination in London.

Searching for the best schedule of investment for the best portfolios

W.99 In the first phase, IRAS-MCS generated portfolios of options without a schedule of investment due to the computational burden of including schedule optimisation together with portfolio optimisation for 153 futures of 78 years at a weekly time-step. However, the schedule of future investment is a key part of water resources management planning, and can be carried out by Scheduling-MCS for a smaller pool of robust portfolios as a secondary optimisation.

W.100 IRAS_MCS portfolios can be resilient to a wide range of droughts. HR Wallingford[20] was commissioned to assess the drought library utilised by IRAS in comparison with the 1:200 droughts used by WARMS2 to develop the deterministic DO surplus that is specified for drought resilience in EBSD+. This allowed better understanding of the significance of occurrence of level 3 and level 4 for IRAS_MCS portfolios.

[20] HR Wallingford (2018). Drought libraries for assessing system resilience to droughts, Report MAM8070-RT003-R1-00.

W.101 Scheduling-MCS takes a portfolio of options and optimises across a new ensemble of 176 resampled *Future Flows* scenarios[21] that reflect the changing climate signal[22] and natural variability of flow conditions to find the best order in which to develop options in five year AMP periods.

W.102 Resampling was performed using local block bootstrapping (LBB) (Paparoditis and Politis, 2002) which was designed to resample time series that show nonstationary (changing trend, e.g. climate change signal affecting hydrology). The original 11 future flow scenarios were resampled 15 times in order to create 176 total scenarios (15 resampled in addition to the original). One scenario contained a severe drought (e.g. three consecutive dry winters). This particular scenario was resampled such that this drought appeared in each 5-year planning time period in the 80-year time series. Resampling was performed such that the original trend in each resampled time series was preserved.

W.103 This scheduling takes place during the stress-testing phase, together with analysis of the additional parameters for revised draft WRMP19 programme appraisal (Section 10-F).

Adaptability testing in EBSD+

W.104 The Adaptability analysis method explained below has been developed for use as part of the revised draft WRMP19 programme appraisal.

W.105 Due to the high uncertainty of key influences such as population growth and climate change, especially over long planning horizons, a significant further analysis for water resource planning is assessment of how any potential proposed programme of investment would respond to futures which differ from the central estimate once construction of options selected for commissioning early in the planning horizon has commenced.

W.106 For WRMP14, sensitivity testing assessed the changes to a single preferred plan[18] against a series of individual influences, allowing such changes from year one of the plan. However, adaptability analysis has expanded sensitivity testing to assess how well each of a shortlist of good value programmes could adapt to a range of possible futures based on single and multiple combined influences after a number of years of fixed initial investment.

W.107 Adaptability analysis allows comparative evaluation of Reasonable Alternative Programmes (RAPs) in terms of potential changes to selected options, costs and resilience.

[21] Prudhomme, C., Haxton, T., Crooks, S., Jackson, C., Barkwith, A., Williamson, J., Kelvin, J., Mackay, J., Wang, L., Young, A. & Watts, G. 2013. Future Flows Hydrology: an ensemble of a daily river flow and monthly groundwater levels for use for climate change impact assessment across Great Britain. *Earth System Science Data,* 5**,** 101-107

[22] The 153 original scenarios were perturbed by climate change influence for the final year of the horizon only. For the 176 new scenarios the climate change influence changes over time.

Developing Real Options Analysis (ROA) and Adaptive Pathways Analysis (APA) into adaptability assessment

W.108 Where a complex problem exists, UKWIR's WRMP guidance advocates the use of advanced decision-making methods such as ROA[23] or APA[24] to better explore the deep uncertainties surrounding the EBSD method of programme development. We have investigated the use of both adaptive pathway and real option methods for solution of more complex planning problems, and have also commissioned research to develop methods to combine river simulation and robust decision making[25].

W.109 Adaptive methods identify a range of portfolios of options and test them against a range of potential futures to satisfy a variety of social, environmental and economic drivers. Adaptive pathways illustrate what triggers or threshold monitoring values indicate the need to move from one portfolio to another at points in the future.

W.110 Real options methods identify a range of potential futures built from a variety of social, environmental and economic drivers and develop a series of optimised programmes of investment to satisfy those futures. ROA incorporates the flexibility and robustness of different types of technology by allowing staged or phased development of options, and therefore increase or decrease capacity of new developments as futures change. ROA identifies the most cost-effective programme of investment which remains robust and flexible to meet the widest range of potential futures.

W.111 However, programme appraisal in Thames Water has moved away from looking for a single solution produced by a decision support tool. We are considering a range of complex technologies with which to address a supply-demand problem in London which includes deep future uncertainty, and as such programme appraisal entails comparative assessment of several programmes of investment using multiple values, to enable expert judgement selection of a preferred plan. As such, Thames Water has developed a hybrid method, combining key aspects of both APA and ROA, which evaluates the flexibility and robustness of an existing candidate programme faced with several more and less challenging futures. This Adaptability analysis is carried out on a shortlist of good value programmes, allowing comparative assessment of the results to support the programme appraisal process towards a final selection, in combination with the other metrics. The steps are outlined in Table W-15.

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[23] Atkins, Possible Applications of Real Options Analysis to Thames Water's revised draft WRMP19, Sept 2016
[24] Kingsborough and Hall, Urban Adaptation Planning: Adaptation Pathways for Water Resources, Jan 2015
[25] Huskova, I., E. S. Matrosov, J. J. Harou, J. R. Kasprzyk and C. Lambert (2016). "Screening robust water infrastructure investments and their trade-offs under global change: A London example." Global Environmental Change 41: 216-227..

Table W-15: Adaptability assessment stages

Step	Adaptability analysis
1	Identify candidate programmes of investment
2	Identify a range of potential futures to assess
3	Identify trigger points for significant changes in investment
4	Generate alternative pathways between trigger points
4	Assess how each programme of investment will adapt across all pathways
5	Assess comparative adaptability of all potential programmes

W.112 The detailed method for testing shortlisted programmes is described in five stages:

- Developing future scenarios
- Selecting decision points
- Defining future pathways
- Testing RAP adaptability across pathways
- Assessing the results

Developing future scenarios

W.113 Adaptability incorporates potential changes to the most likely future supply demand balance (SDB) based on 5 drivers for change to future forecasts (Table W-16).

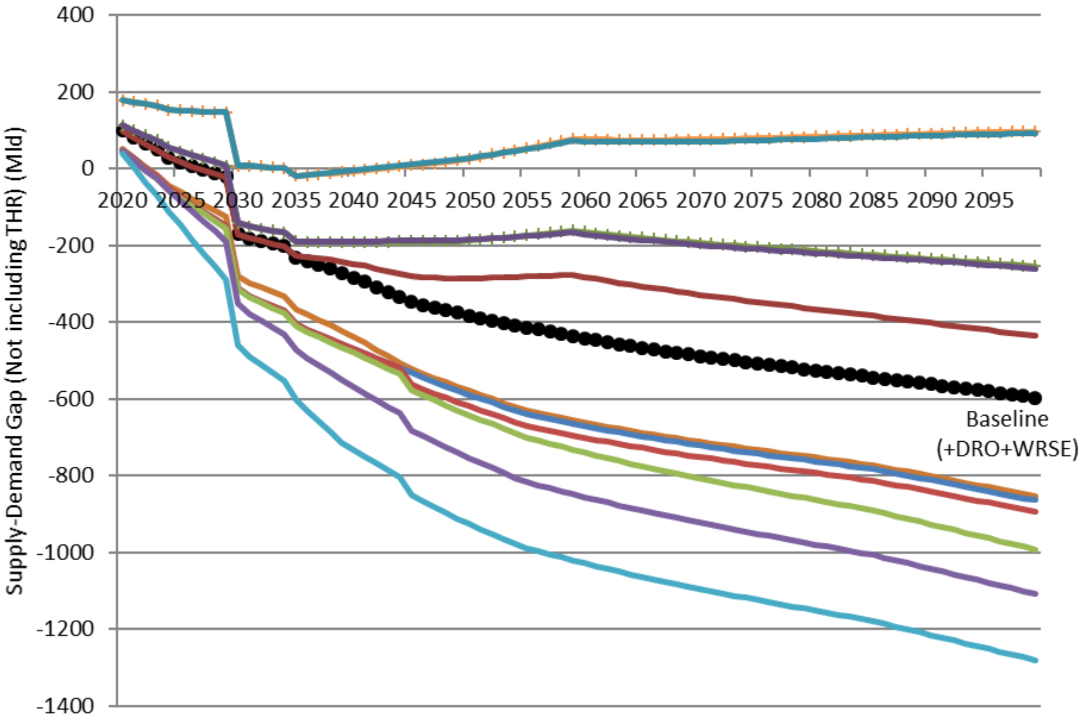
Table W-16: Adaptation drivers for future forecasts

Uncertainty	Alternative dataset	Forecasts (inc BL)
Population	ONS 2016 Trend based forecast High and Low variations	3
PCC forecast	No demand savings from Policy DMP, Future PCC scenarios of 105 and 86 l/head/d by 2065	4
Leakage uncertainty	Assuming that we only reduce leakage by a third by 2050	2
WRSE	Allowing for future regional needs beyond that included in our most likely scenario (Affinity Water 100 Mld at 2037/38)	5
Climate change	Taking the Medium emissions 5% and 95% percentile impact on deployable output, and alternative futures where the impact occurs by 2050 or 2080	5

W.114 A sixth driver, potential legislative changes, was also considered, to take into account the WINEP no deterioration scenario, which could reduce London and SWOX combined WAFU by a further 93Mld. However, the worst-case scenario combining the 5 drivers above would already take the London deficit to 1300Mld by 2100 (Figure W-15 below), which at best would require 300Mld of combined reuse and desalination in London in addition to 1000Mld from combined demand management, reservoir and Severn-Thames transfer. 300Mld of additional reuse and desalination is the conservative limit set by the combined SEA to avoid potential environmental detriment (subject to further assessment) to the Thames estuary. As the only remaining options are further reuse or desalination in London, the only way Adaptability analysis could solve worst-case pathways including WINEP no deterioration is by building possibly detrimental amounts of reuse and desalination. For this reason, WINEP has not been included explicitly as an additional Adaptability driver, although it is possible to assess programmes which reflect WINEP reduction alone or in combination with one or further additional drivers from the Pathways developed from the other drivers. WINEP is also assessed as a stand-alone What-If scenario.

W.115 The divergence from the baseline/ central position for each of these alternative forecasts is depicted in Figure W-34 to Figure W-38 in Annex 4, and the range of scenarios combining those forecasts for London is reproduced in Figure W-15 below.

Figure W-15: London scenario range around baseline (excluding target headroom)



W.116 The range of scenarios for London widens over the planning horizon, and reaches maximum divergence by the end of the planning horizon, with the least challenging having a surplus of 91Mld and the most challenging a deficit of 1281Mld (neither including target headroom). The final baseline SDB sits at a deficit of 597Mld, almost exactly between the two extremes.

W.117 The range of scenarios for SWOX and SWA are shown in Figure W-39 and Figure W-40 in Annex 4. The divergence is shown in Table W-17 below.

Table W-17: Final SDB range across Adaptability scenarios

SDG 2099/2100	London	SWOX	SWA
Minimum	91	49	19
Baseline	-597	-126	-17
Maximum	-1281	-315	-38

W.118 These alternative datasets (charted in Annex 4), both individually and in combination form 726 variations to the baseline supply-demand forecast in each WRZ. Several of the combinations create very similar deficits; rather than assess each alternative future scenario individually, the range of futures in each WRZ was examined to determine when alternative scenarios would require significant changes to a plan, i.e. when a key decision must be reviewed.

Selecting decision points

W.119 Pathways are not developed for each of the potential scenarios, instead they are developed between decision points based on the range of scenarios. Decision points are set where scenarios diverge beyond where a different number of major investments may be required for the separate pathways.

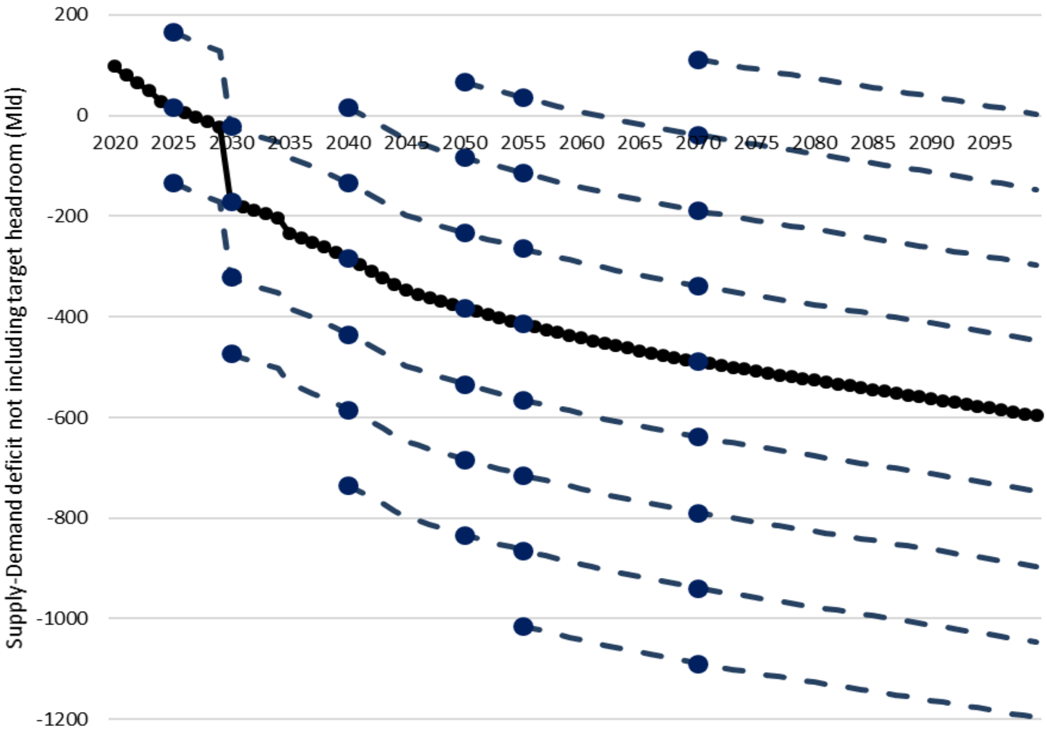
W.120 London WRZ has a relatively low volume of smaller quick-to-implement supply options available in relation to the size of the most likely deficit. In the future, large options will be required to meet most deficits, which will require selection in advance to allow for planning and construction lead time. The decision points for London have therefore been based on when a new large option may be required.

W.121 Water resource management planning is typically updated in five year AMP cycles, and each potential decision point is at the start of each AMP. The majority of large resource options in London have a nominal yield of either 100 or 150Mld, yet the London baseline 'most likely' DYAA forecast averages an increase of over 100Mld deficit per AMP cycle for the first twenty-five years. A large option of 150Mld capacity would therefore be required to ensure there would be sufficient water until the next planning cycle, for any decision point between 2020 and 2045.

W.122 Analysis of the increasing divergence of the scenarios in Figure W-15 at the beginning of each AMP shows that in London between zero and two additional large options may be required in 2025; zero to three in 2030; zero to five in 2040; zero to six in 2050; zero to seven in 2055 and zero to eight in 2070.

W.123 The decision points have been marked in Figure W-16 with large blue markers. All forecasts continuing from a decision point follow the trend of the baseline supply demand balance (not including target headroom); these are displayed as dotted lines, mirroring the baseline forecast shown as the black line with circular markers.

Figure W-16: London decision points mirroring baseline

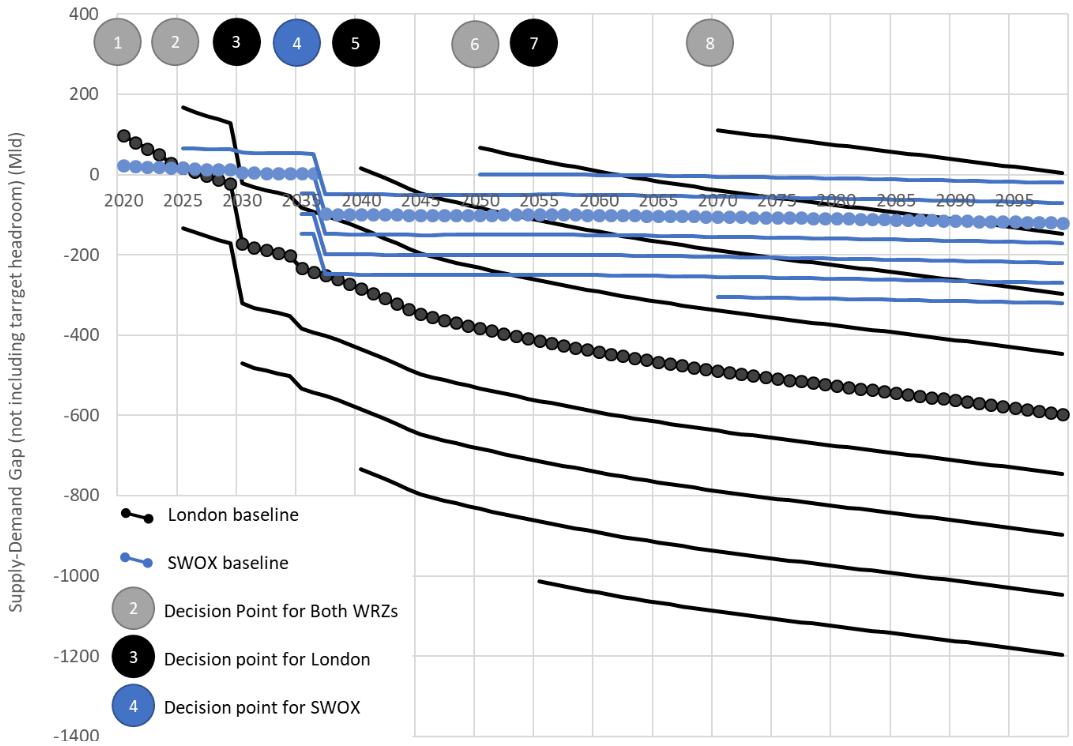


W.124 In SWOX, the size of potential new resource options is much more varied, as should the Severn transfer pipeline be built, the support options to provide resource in critical period can cover a range of deployable outputs. 50Mld has been selected as the SWOX decision point gap, representative of the smallest feasible size of initial investment in the STT. Figure W-39 in Annex 4 shows the range of SWOX scenarios around baseline, for which the SWOX decision points are selected. The main difference to London is the requirement for an additional set of decision points in 2035.

W.125 SWA zone has fewer options available; the main selection is the size of transfers from SWOX. The zone requires no further decision points beyond those selected for London and SWOX, branching at the same dates, but a gap of 10Mld has been selected to best map the SWA scenario range using the same number of branch points as for the other zones.

W.126 In total there are 8 branch points with 9 final branches (including the baseline) based on the London (black lines) and SWOX (blue lines) scenario ranges (Figure W-17).

Figure W-17: Adaptability decision points and branches, London & SWOX

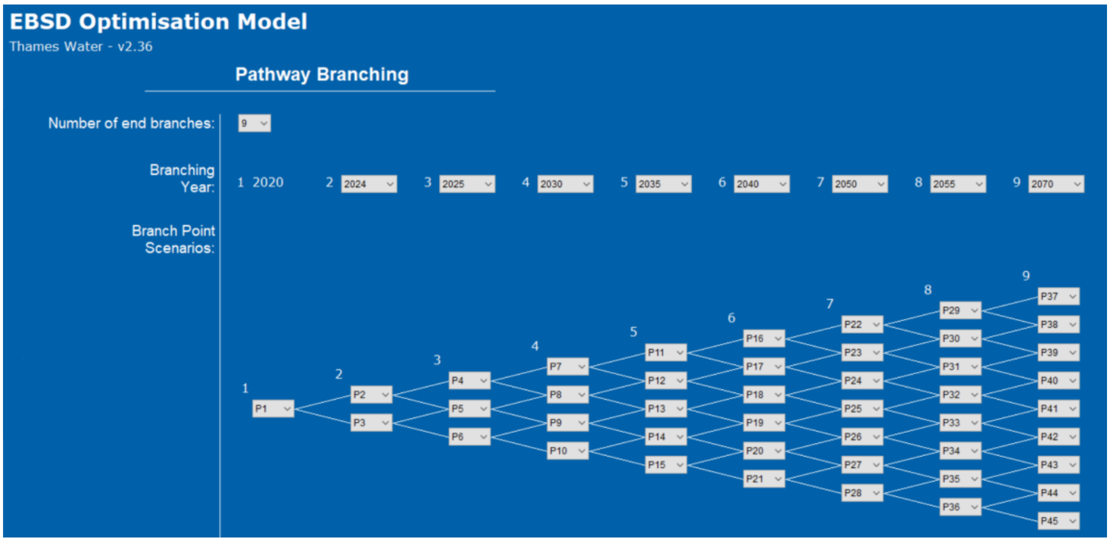


W.127 A useful note from this decision point analysis is that with the size of the majority of options (phased or stand-alone) available for London WRZ (150Mld), a decision as to whether or not to build a new large option may be required each AMP for four out of the next five. As combinations of new reuse and desalination options providing more than 300 Mld in London could cause detrimental environmental effects on the tideway, at least one strategic resource (reservoir or transfer) will be required to meet the London baseline alone, or both strategic resources should the future demand for water or drought resilience increase from the current baseline.

Defining future pathways

W.128 The eight decision points mark where pathways derived from the Adaptability scenarios divide. The decision points and branches in Figure W-17 are mapped in EBSD+ with an additional 'sleeping' branch point in 2024 to allow the branch number to increase incrementally by one at each branch point, a necessity for generation of pathways within the model. The two 2024 branches are identical to the baseline. Similar 'sleeping' branches occur in SWOX in 2030, 2040 and 2055, when branching is driven by the London problem, and in London in 2035 when branching is driven by the SWOX scenarios; all mirror the baselines. This leads to the pathway tree presented in Figure W-18.

Figure W-18: EBSD+ decision tree for Adaptability pathway generation



W.129 For each WRZ, 45 supply and demand forecasts are input into the model, i.e. P1 (baseline) to P45. All forecasts mirror the gradient of the zonal P1 baseline supply demand balance (not including target headroom). The lines in Figure W-17 display the supply-demand forecasts for London and SWOX.

W.130 All pathways begin with the same baseline supply and demand forecasts in all zones, and at each subsequent decision point each pathway divides, moving either to the branch above or the branch below. This generates 256 alternative future pathways to the final nine endpoints (Annex 5).

Testing RAP adaptability across pathways

W.131 A selected RAP is uploaded to the Adaptability module within EBSD, for analysis across the pathways in Figure W-18. Selection of the RAP occurs at Branching Year 1 (2020). The next decision point (Branching Year 2) is in 2024/25; any option within the input RAP for which construction starts before 2024/5 is fixed before the first Adaptability optimisation. As a result, the major investment decisions made in 2020 are maintained throughout the Adaptability analyses for all RAPs, enabling evaluation of how any of those investments would adapt to the multiple different futures represented by the pathways (Table W-18).

Table W-18: Initial investment in each RAP maintained in Adaptability analysis

RAP	Deephams Reuse	Oxford Canal	Severn Transfer[26]	Reservoir	Beckton Desal	Beckton Reuse	Small options	DYCP[27] Capacity of Initial Options
	Mld	Mld	Mld	Mld	Mld	Mld	Mld	**Mld**
NearO_RES		11	54		142		22	**229**
MultiObj_RES		11	60			190	32	**293**
Least Cost	45			253			3	**301**
MultiObj_FP	45	11		253			3	**312**
Min_IGEQ	45			294			9	**348**
NearO_TP				294	142		0	**436**

W.132 At each Branching point a new least-cost optimisation is carried out to the end of the planning horizon for each pathway which starts at that Branch Point, using the supply and demand forecasts which start from that Branching Point, and with year 1 of the baseline target headroom (THR) forecast reset to start from that date. In the baseline, THR year 1 corresponds to 2020 in the supply and demand forecasts.

W.133 For example, Pathway_N180[28] is created by nine progressively shorter optimisations using the supply and demand forecasts P1, P3, P6, P9, P13, P19, P26, P33, P42.

W.134 For assessment of the Least Cost RAP, investment options for which construction has started before 2024/5 are fixed (Table W-18: Deephams reuse, 125Mm3 reservoir, 3Mld of small options). EBSD+ then optimises selection and utilisation of further options from 2024/5 to 2099/2100 using supply and demand forecasts P3 with the target headroom year 0 reset to 2024/5.

W.135 The analysis moves to the next decision point (2025/26). Options for which construction begins in 2024/5 are added to the fixed option list, and a second optimisation is run for the remaining 75 years using forecasts P6, with the THR year 0 reset to 2025/6.

W.136 The analysis moves to the next decision point (2030/1). Options for which construction begins before 2030/1 are added to the fixed options, and the optimisation is repeated using supply demand forecasts P9 with the THR year 0 reset to 2030.

W.137 This process is repeated for each decision point in Pathway_N180 until the deficit in 2099/2100 of forecast P42 is solved (Figure W-19: -933Mld not including THR).

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[26] The DYCP capacity of the STT represents the resource options selected. The pipe capacity is 300Mld.

[27] DYAA in London

[28] Pathway_N180 represents the additional WAFU requirement for resilience to a 1:500 drought, the results of which are presented in Appendix X.

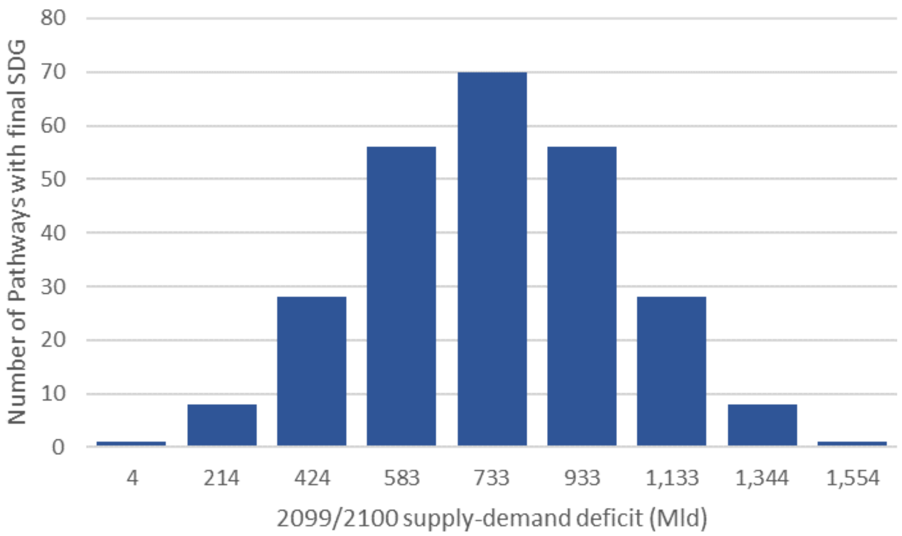
Table W-19: Repeated Optimisations to evaluate Pathway_N180

Supply forecast	Demand forecast	Target headroom forecast year 0	Optimisation horizon (years)
P1	P1	2020/1	80
P3	P3	2024/5	76
P6	P6	2025/6	75
P9	P9	2030/1	70
P13	P13	2035/6	65
P19	P19	2040/1	60
P26	P26	2050/1	50
P33	P33	2055/6	45
P42	P42	2070/1	30

W.138 These progressive optimisations are repeated until 256 programmes are produced which adapt the original fixed investment decision to the changing futures. Each programme has undergone nine optimisations in progression as per Pathway_N180 in Table W-19.

W.139 Because of the branching method for pathway generation, the distribution of pathways reaching each final SDB is normal about the baseline scenario (Figure W-19).

Figure W-19: Distribution of the 256 pathways to each final SDB not including THR (combined London, SWOX and SWA zones)



W.140 This distribution reflects the current understanding of the probability of each of the final supply-demand deficits being reached.

W.141 The assessment is repeated for each RAP to produce 256 adaptations of the baseline programme.

Testing the results

W.142 There are three major outputs of interest when assessing how any programme will adapt to different futures:

1) What is the risk that supply will not meet demand?
2) What is the risk off future cost increase?
3) What is the risk of building redundant assets?

W.143 EBSD+ records the options selected, costs, SDB failures, utilisation and remaining options available for each of the 256 pathways, for comparative analysis of different initial programmes of investment. The main parameters reported for each RAP are:

- Range of costs for all 256 programmes
- Range of standby costs for all 256 programmes
- Frequency and severity of failures to meet THR in all 256 programmes

Cost Range

W.144 Cost is the total NPV of each programme, including utilisation and carbon, using the same input data and calculation method as the cost calculation for programme development.

Standby Cost Range

W.145 When planning for long term assets to provide resilience, another aspect to consider beyond total investment cost is the cost of maintaining assets on standby. This has been calculated in each year as the fixed opex and capital maintenance costs for any asset not utilised in that year, summed across all years for each pathway then converted to Net Present Value (NPV).

Failure frequency and severity

W.146 There are abrupt changes in SDB built into the Adaptability paths, to test the ability of each programme to adapt to future events. Failures are recorded as the proportion of demand plus THR met by available WAFU in each year, for each pathway. For the majority of years and pathways the result is 1.

W.147 Due to the complexity of the outputs, and the small shortlist of programmes for comparison, combining the Adaptability outputs into a single metric would not aid the decision-making process.

W.148 The option selection, cost and resilience outputs from the 256 programmes for each RAP are analysed in comparison and separately, as shown in Appendix X.

Programme appraisal: visualisation and selection decision support tool (DST)

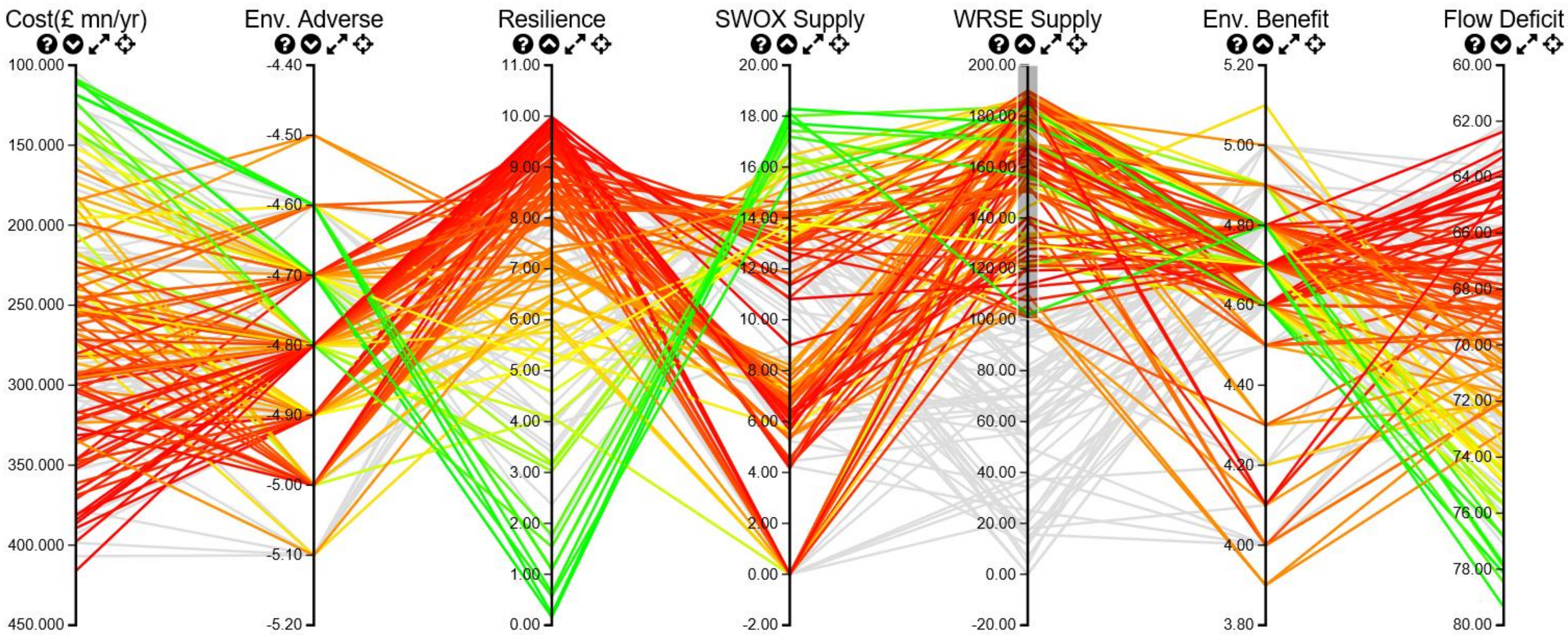
W.149 Programme appraisal requires analysis of available solutions using expert judgement, in order to select a shortlist of good value plans for further testing. With the generation of multiple feasible programmes to be evaluated with multiple metrics, a method to assist in the filtering out of less favourable solutions and analysis of the data behind all metrics becomes necessary.

W.150 The programme appraisal process also needs to be as robust and transparent as possible; for this reason a web-based tool, PolyVis, has been developed to enable sharing, visualisation, filtering and interrogation of the programmes and portfolios output by the EBSD+ and IRAS models between a panel of both internal and external experts (Figure W-4). The tool also allows the recording and sharing of the reasoning by which experts reach their conclusions during the selection process.

W.151 PolyVis has three main levels of information presentation:

- Sheet pages, where entire libraries of feasible programmes are displayed for comparison and filtering using parallel axis plots of programme metrics
- Plan pages, where individual programmes can be examined in detail based around three formats:
    - Tabular data listing options, start dates, option metrics, etc.
    - Charts of investment plans in relation to the deficit
    - Maps of investment plans
- Option/ Metric pages, where background data is shown which details the information from which the option metrics have been developed

Figure W-20: Parallel axis plot of output programmes: filtering

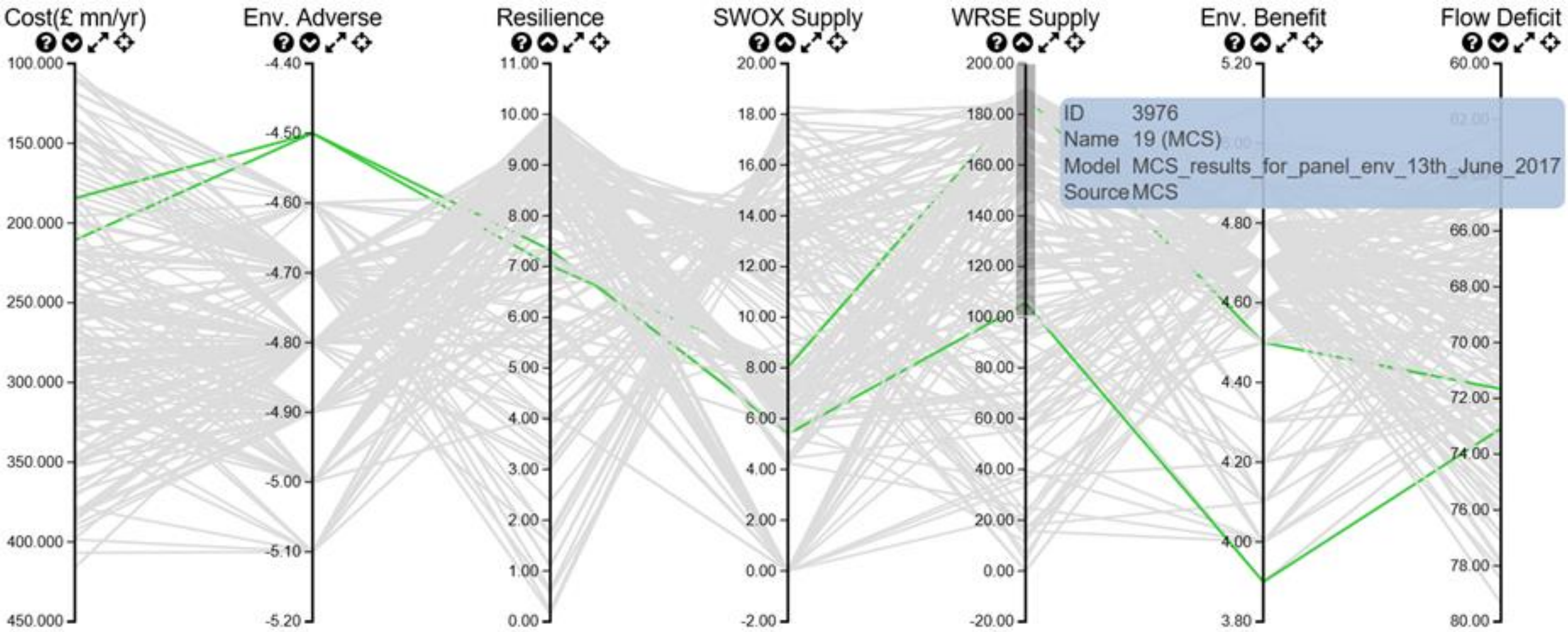


W.152 The parallel axis plot is primarily used to review and filter the large number of potential programmes (50-100) which could solve the supply-demand problem for revised draft WRMP19 (Figure W-20).

W.153 Each line represents a programme, and so comparison and filtering of different programmes across the metrics can be carried out to narrow down the set of programmes in which a particular user is interested.

W.154 In Figure W-20 a colour filter has been applied to the Resilience metric and a selection filter applied to the WRSE supply axis, filtering out all programmes with WRSE supply below 100 Mld (grey lines have been filtered out).

Figure W-21: Parallel axis plot of output programmes: selection



id	planname	outputname	modeltype	COST
3976	19 (MCS)	MCS_results_for_panel_env_13th_June_2017	MCS	£210.77 mn/yr
4022	65 (MCS)	MCS_results_for_panel_env_13th_June_2017	MCS	£184.53 mn/yr

W.155 Selecting the two remaining programmes with the lowest adverse environmental grade highlights both (Figure W-21), showing the specific programmes (or in this case, MCS portfolios) in the table below the chart. The popup that appears on mouseover of the line with WRSE supply greater than 180 Mld shows that this is the higher cost programme, 19(MCS). Clicking on that programme will take you to the plan page (Figure W-22).

Figure W-22: Plan page of option details for a specific programme

Plan "19 (MCS)"

Option Details | Supply Demand Gap | View On Map

Option details

Show 10 entries | Column visibility | Search:

Name	Type	Max Capacity
CON_Surbiton intake capacity increase	Conveyance	100.00
RES_Reservoir Abingdon 125 (Lon only)	Reservoir	125.00
RWP_Raw Water Transfer Mythe 15 MLD	Raw Water Purchase	15.00
RWP_Raw Water Transfer Upper Severn Vyrnwy 180 MLD (2 zone Lon 170MLD)	Raw Water Purchase	180.00
RWP_Raw Water Transfer Upper Severn Vyrnwy 180 MLD (2 zone SWOX 20MLD)	Raw Water Purchase	180.00
CON_Direct River Abstraction - Teddington to Thames Lee Tunnel Shaft 300 MLD	Conveyance	300.00
CON_Mogden to Teddington 300 MLD	Conveyance	300.00
CON_Raw Water Transfer Deerhurst to Culham 300 MLD (2 zone Lon 290MLD)	Conveyance	300.00

W.156 Programme details can also be viewed in terms of investment scheduling in relation to the forecast supply demand gap (Figure W-23) and investment map (Figure W-24) to aid understanding.

Figure W-23: Timeline of investment options and yield

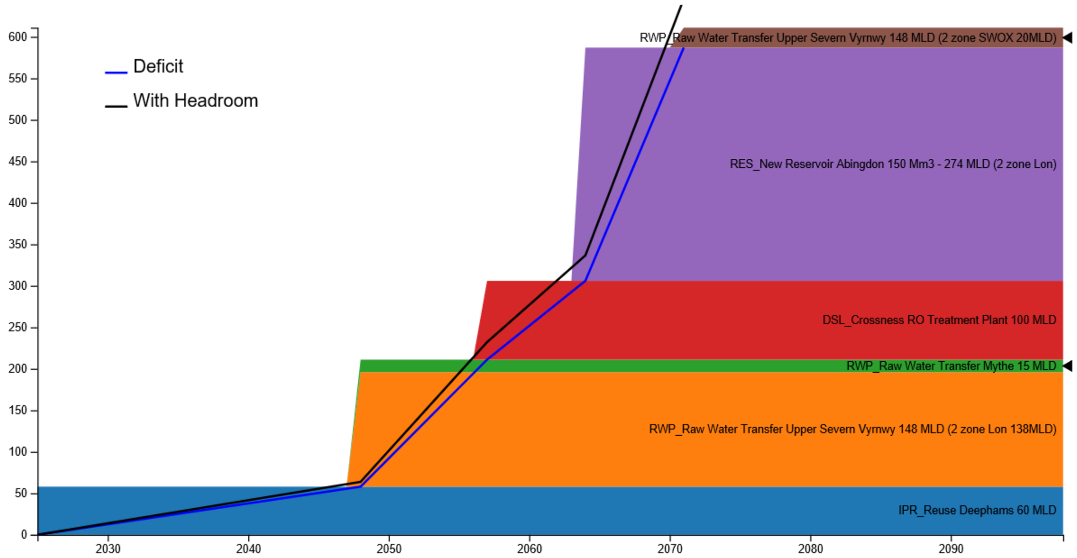
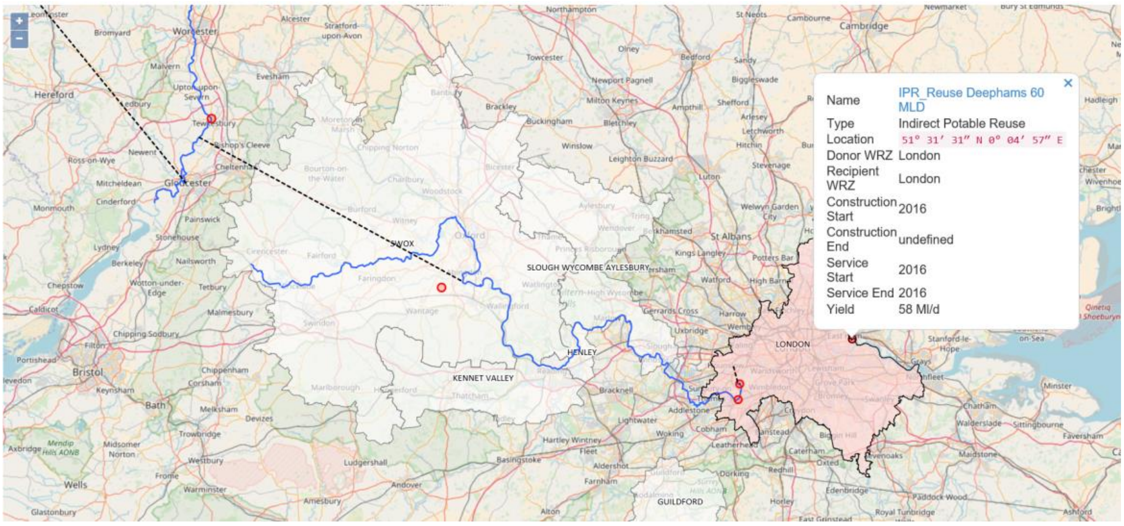


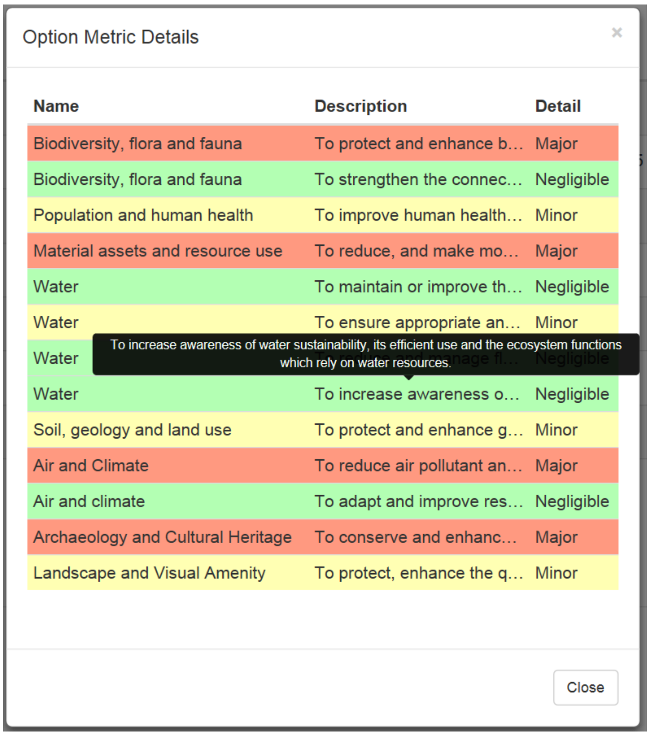
Figure W-24: Map showing proposed investments



Option/Metric pages

W.157 The background data from which all metrics are developed for all options is also available in PolyVis, for example Figure W-25 holds the Adverse Environmental Impact Details for all categories in the Strategic Environmental Assessment (SEA) for a single Indirect Potable Reuse (IPR) plant.

Figure W-25: SEA category details for single IPR



Name	Description	Detail
Biodiversity, flora and fauna	To protect and enhance b…	Major
Biodiversity, flora and fauna	To strengthen the connec…	Negligible
Population and human health	To improve human health…	Minor
Material assets and resource use	To reduce, and make mo…	Major
Water	To maintain or improve th…	Negligible
Water	To ensure appropriate an…	Minor
Water	[illegible]	Negligible
Water	To increase awareness o…	Negligible
Soil, geology and land use	To protect and enhance g…	Minor
Air and Climate	To reduce air pollutant an…	Major
Air and climate	To adapt and improve res…	Negligible
Archaeology and Cultural Heritage	To conserve and enhanc…	Major
Landscape and Visual Amenity	To protect, enhance the q…	Minor

W.158 This filtering and selection DST is used to assist in shortlisting good value plans for further scrutiny.

W.159 Each shortlisted programme is subject to a plan-level SEA to ensure that cumulative environmental effects are considered fully, and further testing against different future scenarios. The programme level SEA and Adaptability results are considered together with the development metrics in order to enable robust selection of a preferred plan.

W.160 Selection of the preferred plan is therefore enabled with understanding of all the values behind each programme. A central audit trail of all decision steps taken allows tracking of the decision making process by all users.

Conclusions

W.161 In line with the guidance, we have developed methods of programme appraisal and DSTs that are commensurate with the characterisation/level of concern of significant supply demand deficit in each of our WRZs.

W.162 WRZs of Low concern (Kennet Valley, Guildford and Henley) are assessed using the WRMP14 EBSD approach of single objective least cost optimisation with subsequent manual consideration of other parameters.

W.163 WRZs of Moderate (SWA) and High (London and SWOX) concern undergo enhanced programme appraisal using EBSD, EBSD+ and IRAS models that enable multi-criteria optimisation and system simulation.

W.164 IRAS_MCS has produced a suite of portfolios from which a selection has been made of those to be scheduled across the planning horizon for investment planning.

W.165 A key aim of revised draft WRMP19 programme development modelling is to achieve acceptance and understanding of simulation modelling by enabling full comparative assessment of these outputs with EBSD+ outputs. This assessment is presented in Section 10 and Appendix X.

W.166 EBSD+ and IRAS_MCS have produced over 100 potential programmes, each with their own advantages and disadvantages across the metrics. A visualisation tool, Polyvis, has been developed to aid the internal and external subject matter experts in assessing and sharing shortlisted selections.

C. Part C: Metrics

Summary

W.167 The WRPG presents clear guidance for water companies to move from least cost development of WRMPs towards a best value plan for WRMP19, taking into account several additional metrics beyond financial cost. This document describes the reasons for selection of the metrics which we have embedded within our programme development and selection processes, and the methods developed for quantification of those metrics.

W.168 There are four sections within Part C:

1) WRMP19 Metric Selection for programme development and appraisal
2) WRMP19 Metric Definition and Quantification
3) Programme Selection through analysis and comparison of metrics
4) Conclusions and further work

Revised draft WRMP19 metric selection

W.169 Metrics have been developed both to provide understanding of the value of any potential programme of investment for WRMP19, and to direct programme development models to search for good value programmes that diverge from the least cost. The key requisite for selection of metrics was therefore determination of what we value. There are three sources from which the value of a WRMP has been distilled:

1) Our WRMP14 programme appraisal process[29]
2) The WRPG
3) Our WRMP19 option selection and screening process

W.170 The values identified in each of the three sources are described in W.171 to W.180, and W.181 to W.184 shows how these were aligned to define the metrics for WRMP19.

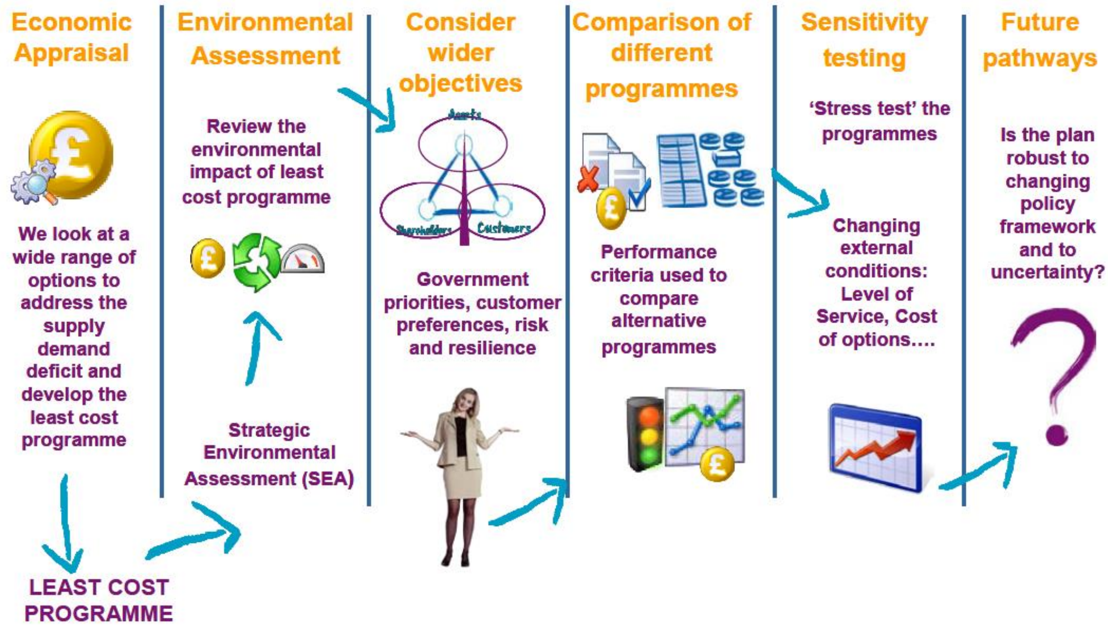
[29] Thames Water, Water Resources Management Plan, Section 8: Programme appraisal, 2014

WRMP14 programme appraisal process values

W.171 Our WRMP14 used an EBSD model to find the least cost plan to meet the supply demand problem within each of our WRZs. The least cost plan was then further appraised in terms of a series of parameters beyond financial cost, until the preferred plan was identified. This appraisal process, stepwise from least cost, assessed a series of additional values listed below and shown in Figure W-26.

- Environmental impact (beyond those monetised using Benefits Assessment guidance)
- Government priorities
- Customer preference
- Risk
- Resilience
- Changing external conditions (level of service, supply chain costs)
- Future pathways (legislation changes, forecast uncertainty, contingency planning)

Figure W-26: WRMP14 programme appraisal process



***Revised draft WRMP19 guidance*[30]**

W.172 The WRPG Guiding Principles set out the key policy priorities which government expects WRMPs to address. Table W-20 presents and groups relevant extracts from the guidance document and summarises the aim of each.

Table W-20: WRMP19 guidance: Aims of a plan

Extract from guidance on purpose of a plan	Summary/value
• Secure the long-term resilience of the water sector • Value of resilience for customers • Assess resilience to other hazards such as flooding and freeze-thaw impacts and the overall resilience of your network	Resilient – to further hazards than drought
• Can manage the challenges and uncertainties of the future • Sufficiently flexible to accommodate reasonably predictable changes to regulation such as abstraction reform and competition	Flexible – to future uncertainties and challenges
• Informed by your customers' views • Acting collaboratively: supporting the outcomes from the WRSE Group plus other collaboration e.g. transfers between water companies to free up surplus water and improve resilience, sharing of joint resource developments, especially if there is a multi-company or regional benefit, and other sectors	Collaborative – working with customers, other water companies and other sectors
• Best value to customers over the long term • The balance of investment bearing in mind the long-term needs of customers • Demonstrate how you will promote water efficiency and leakage control • Continue the trend of reducing overall demand for water	Long-term - for customers' costs, and demand and leakage reduction
• Demonstrate how you value nature in your decisions • Consider where you can provide new and innovative opportunities for investment in our natural assets • Play a substantial role in contributing to local environmental improvement	Value nature

[30] Department of Environment, Food and Rural Affairs (Defra), Guiding principles for water resources planning, May 2016

WRMP19 Option screening process

W.173 Options which may be used to increase supply or decrease demand and therefore could form part of a solution to a supply demand problem are identified and then either developed or screened out as part of the options development process.

W.174 The option screening is carried out using the following dimensions[31]:

- Environment and social
- Cost
- Promotability
- Flexibility
- Deliverability
- Resilience

Environment and social

W.175 The WRMP falls within scope of the SEA Directive. Evidence from the SEA, Habitats Regulations Assessment (HRA), and Water Framework Directive (WFD) Assessment is reviewed into a single indicator of likely environmental benefits and dis-benefits.

Cost

W.176 Cost screening is carried out through comparison of option Average Incremental Cost plus monetised impact of carbon emissions against a benchmark value. The comparison considers uncertainty ranges as well as the relative magnitude of point estimates.

Promotability

W.177 Promotability considers the scheme up to the point of planning permission being granted and includes professional judgement of:

- Synergies (e.g. synergies with water resource needs of other WRZs in the South East and synergies with third party developments)
- Customer preference (e.g. in relation to wastewater reuse, including views of the Customer Challenge Group);
- Local acceptability (e.g. in relation to planning challenges);
- Regulatory acceptability (including the Drinking Water Inspectorate (DWI), Environment Agency, Ofwat); and
- Wider stakeholder acceptability.

[31] Mott MacDonald, Fine Screening Report, January 2018.

Flexibility

W.178 Assessment of how flexible an option is, in relation to:

- Lead time: WRMP14 lead times were used to inform this assessment;
- Phasing: Potential for the scheme to be incrementally built and/or commissioned;
- Adaptability: Whether the scheme is extendable once built; and
- Ramp-up: How quickly the system can respond to changes in demand over its operational life.

Deliverability

W.179 The Deliverability criterion considers the option from the planning permission stage to commissioning and operation. It includes assessment of construction, technology and other implementation risks. Both the WRMP14 Delivery and Solution Confidence Scores are used as part of this assessment.

- **Constructability:** Uncertainties surrounding construction e.g. unknown technologies, land availability, or contamination risks
- **Operability:** Whether there is a track record of successfully using the technology and if it is a dependable and proven technology
- **Dependencies:** Dependencies on other assets, activities or third parties
- **Data confidence:** Reliability and uncertainty of design data and deployable output (DO) assessment methodologies, etc

Resilience

W.180 The Resilience criterion considers the option from the operation stage into the future. It is an assessment of confidence that the option at the given cost will provide the stated DO, with the required water quality in the future, and includes:

- Vulnerability to climate change and severe drought
- Resource predictability
- Contribution to the wider system's resilience to outage
- Vulnerability to other 'failure modes' (e.g. pollution events, power outages, chemicals commodity chains and terrorism)
- Vulnerability to regulatory changes (e.g. abstraction reform)

Revised draft WRMP19 Metric selection

W.181 Distilling the values used in WRMP14, the option screening process for WRMP19, and the WRMP19 guidance, we have selected eight metrics for EBSD+ development and evaluation of WRMP19 programmes (Table W-21).

Table W-21: WRMP19 metrics

WRMP19 Metric	WRMP14 Programme Appraisal	WRPG Guiding Principles	revised draft WRMP19 Option Screening
Cost	Cost	Cost	Cost
Adverse Environmental Impact	Environment	Nature	Environment and Social
Environmental Benefit			
Deliverability	Risk		Deliverability
Resilience	Resilience	Resilience	Resilience
Intergenerational Equity	Government Priorities	Long-term	
Preference	Customer Preference Government Priorities	Collaborative	Promotability
Adaptability	Changing External Conditions Future Pathways	Flexibility	Flexibility

W.182 During programme development and shortlisting, adverse and beneficial environmental impacts of each option are optimised and reported separately, both metrics derived by the same method based on the SEA approach (W.200). Two metrics are required because otherwise combination of a major adverse and major beneficial effect from a single option may imply a negligible environmental impact overall, which is clearly not the case. For selection of a preferred plan, a full plan-level SEA is carried out for shortlisted programmes, with environmental impact again considered as a whole.

W.183 Adaptability is a complex, computationally intense analysis of the reaction of a potential plan to changing futures akin to sensitivity testing of a preferred plan. Due to the complexity and computational intensity, Adaptability has not been used as a metric for development and assessment of potential programmes, but instead gives more insight when comparing good-value shortlisted programmes for assessment of the preferred plan.

W.184 Hence for programme development and shortlisting there are seven metrics, and for plan selection there are a different seven metrics:

Table W-22: Revised draft WRMP19 metric utilisation

WRMP19 metric	Programme development (optimisation)	Programme shortlisting	Programme selection
Cost	Minimise cost	Programme NPV	Programme NPV
Adverse Environmental Impact	Minimise adverse impact	Programme environmental cost	Programme-level SEA
Environmental benefit	Maximise benefit	Programme environmental benefit	
Deliverability	Minimise risk	Programme deliverability	Programme deliverability
Resilience	Maximise Resilience	Programme Resilience	Programme Resilience
Intergenerational equity	Maximise intergenerational equity	Programme intergenerational equity	Programme intergenerational equity
Preference	Maximise type of option preference	Customer Preference for Programme	Customer Preference for Programme
	Optimise LoS preference		
Adaptability	N/a	N/a	Programme Adaptability

Defining and quantifying revised draft WRMP19 metrics

W.185 The above eight metrics are used to compare and select between different potential investment programmes developed with EBSD+, and hence comparable scores are required for each metric for each programme.

W.186 In this section we take each metric in turn and describe how each is scored.

Cost

W.187 In EBSD the cost metric is expressed as the NPV of the total cost of a proposed programme across the planning horizon, developed by summing the cost of each new option in each year and then calculating the NPV using the Social Time Preference Rate (STPR) for discounting[32].

W.188 The cost of each option includes:

- Capital cost, fixed operational cost, variable operational cost, monetised carbon
- Most likely estimates of cost risk

[32] HM Treasury (2003); Green Book Treasury Guidance, revised 2011

W.189 Environmental and social costs are not monetised as they have negligible relative contribution in comparison with capital costs, and are covered by a separate qualitative metric.

$$Cost_j = \sum_{y}^{Y80} \left(\sum_{i}^{I_j} \left(Capex_{i,y} + FOpex_{i,y} + VOpex_i \times Util_{i,y} + Carb_{i,y} \right) \right) \div (1 + STPR)^{(y-y0)}$$

W.190 A full description of how supply option costs are derived is given in Section 7: Appraisal of resource options, with a short synopsis included below. Demand option costs are explained in Section 8: Appraisal of demand options.

Capital costs

W.191 Initial capital expenditure (capex) is estimated using a combination of cost models and bottom-up costing where models do not exist. Recurring capex is estimated using asset lives for different types of component, and therefore maintenance costs of replacing components are included in the capex costs.

Operating costs

W.192 Operational expenditure (opex) is calculated from quantities (e.g. units of power, employees, maintenance labour costs and chemicals), and unit rates. Opex can include fixed annual costs to maintain an option ready for use (FOpex), and variable costs per unit of water produced (VOpex), allowing the cost impact of utilisation of assets to be calculated for all years.

W.193 Asset utilisation is ranked by the variable opex per Mld of all new and existing resource options, each being selected in turn from least to most expensive to provide sufficient water for the demand for the year under evaluation.

$$Vopex_y = \min_{SDG_y \leq \sum DO_i} \sum_i VOpex_i \times DO_i$$

Carbon costs

W.194 Embodied carbon estimation uses our existing models or measures of carbon intensity (i.e. kgCO_2e per £ of capex by asset type). Operating carbon estimation uses emissions factors (kgCO2e/unit) for power, chemicals etc. Monetisation of carbon distinguishes between traded/non-traded price and grid emissions factors to take account of gradual decarbonisation of grid energy.

Most likely estimates of cost risk

W.195 Known risks are identified through a risk register for both capex and opex.

W.196 Unknown risks are allowed for capex only using optimism bias with a most likely value determined using the Green Book method (HM Treasury 2003).

Difference between cost within EBSD+ and MCS models

W.197 IRAS_MCS calculates the cost of a final portfolio using the same costs as EBSD+, although the costs are annuitized for portfolio comparison and optimisation. This means the IRAS_MCS portfolio costs are expressed as £ million/ year. After selection and scheduling, IRAS_MCS programme costs are also discounted and presented in £ billion NPV, and should therefore be comparable with EBSD costs.

W.198 There will be additional minor differences in the variable opex and variable carbon due to the fact that the EBSD+ model works in yearly timesteps and the IRAS_MCS model in five year periods analysed over weekly timesteps. Moreover, IRAS_MCS planning horizon is 78 years whereas EBSD is 80.

EBSD Optimisation using cost metric

W.199 EBSD minimises the total Net Present Value of any programme j containing a selection of options which can satisfy the predetermined supply demand gap in a WRZ or combination of WRZs:

$$\text{Minimise}\left\{\sum_{y=0}^{80}\left(\frac{1}{(1+STPR)^{(y-y_0)}}\right)\sum_{i}^{I_j}\left(Cost_{i,y}\right)\right\}$$

which gives a programme cost:

$$Cost_j = \sum_{y=0}^{80}\left(\frac{1}{(1+STPR)^{(y-y_0)}}\right)\sum_{i}^{I_j}\left(Cost_{i,y}\right)$$

Environmental impact

W.200 From the SEA for each option two grades are developed which can be used as a guide to the overall environmental impacts, both adverse and beneficial, of development and operation of that option.

W.201 Option grades between 0 (no impact) and ±10 (major impact to several receptors), are combined within the programme development models to enable a general understanding of the relative environmental impacts of each programme, and this enable comparison during programme appraisal. A full SEA-level assessment has been carried out for shortlisted programmes to ensure full understanding of the combined environmental impacts of the options.

W.202 Development of the option level environmental metrics is carried out after an initial screening of options to see whether they meet WFD and HRA requirements. Those which pass screening are subject to a SEA to qualify the socio-economic impact of construction and operation.

Figure W-27: Significance matrix used to assess effects of each scheme option on each SEA objective

Significance of Effect		Value/ sensitivity of receptor		
		High	Medium	Low
Effect magnitude	High	Major beneficial / Major adverse	Major beneficial / Major adverse	Moderate beneficial / Moderate adverse
	Medium	Major beneficial / Major adverse	Moderate beneficial / Moderate adverse	Minor beneficial / Minor adverse
	Low		Minor beneficial / Minor adverse	Negligible

Key

Significance of effect is dependent on vale/sensitivity of receptor

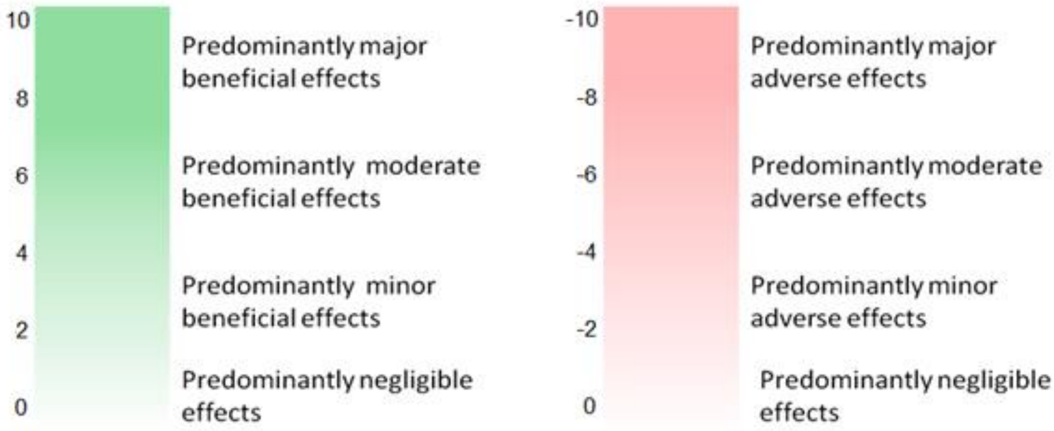
W.203 For each SEA objective, an effects assessment is determined against a significance matrix (Figure W-27) which takes account of the value/sensitivity of the receptor (e.g. air quality, river water quality, landscape value) and the magnitude of the assessed effect. This significance matrix comprises effects from 'major beneficial' to 'major adverse'. Hatching has been added to the box relating to low magnitude and high value as this could result in a greater than 'moderate' effect dependent on the sensitivity/value of the receptor. These effects are reported in the final column of the assessment matrix.

W.204 The assessment matrix provides information on the magnitude of effects and value/sensitivity of receptors. It also identifies the scale of the effects (spatial extent and/or population size affected) and their permanence (e.g. temporary, short-term or permanent). Scale and permanence are taken into account in confirming the effects assessment assigned for each SEA objective.

W.205 Varying levels of uncertainty are inherent within the assessment process. The assessment seeks to minimise uncertainty through the use of expert judgement. The level of uncertainty for the scheme assessment for each SEA objective is provided in the assessment matrix. Where there is significant uncertainty which precludes an effects assessment category being assigned, an "uncertain" label is applied to that specific SEA objective.

W.206 Based on this qualitative (supported by detailed quantitative data) assessment approach, two values referred to as "grades" have been assigned to each option or option element by the SEA expert assessors using a scale of +1 to +10 for overall beneficial effects across the SEA objectives and -1 to -10 for overall adverse effects across the SEA objectives (Figure W-28).

Figure W-28: Qualitative grading to reflect environmental and social effects of each option



W.207 Where effects across the SEA objectives are predominantly negligible a grade of 0 is applied to both beneficial and adverse effects grades. The numerical grades therefore reflect the qualitative assessment. A commentary explaining the determination of the overall numerical grades given for each scheme will be provided at the top of the assessment matrix to explain how they have been assigned.

Programme environmental assessment

W.208 The combination of option-level adverse and beneficial environmental grades into a single score for each per programme is a simple sum of the grades for all options and elements selected:

$$Env_j = \sum_{i=1}^{I_j} Env_i$$

where i is any option or option element selected for programme j.

W.209 Once the programme appraisal modelling has been completed and a smaller number of shortlisted programme options have been determined, the performance of each of these potential programmes is assessed further using the detailed SEA option appraisal data and applying qualified expert judgement, based where practicable on the quantified data collected.

Difference between environmental impact metrics within EBSD+ and MCS models

W.210 As an initial coarse understanding of the relative levels of environmental impact of a wide range of potential programmes, EBSD+ sums the scores for all options.

W.211 MCS uses the same method to include environmental grades for selected options.

Optimisation using environmental metrics

W.212 IRAS includes both environmental grades as objectives in the multi-criteria search, to minimise adverse environmental impact and maximise environmental benefit. EBSD+ also minimises adverse environmental impact as a single-objective optimisation.

$$\text{Minimise}\left\{\sum_{i}^{I_j}(Env-_i)\right\}$$

W.213 Maximising environmental benefit alone, however, results in the optimiser selecting all options with any environmental benefit, and over-engineering a solution. As such, the Maximisation optimisation has been reversed to minimise the lack of environmental benefit for solutions that can solve the supply-demand gap:

$$\text{Minimise}\left\{\sum_{i}^{I_j}(10-Env+_i)\right\}$$

which gives a programme environmental grade:

$$Env+_j=\sum_{i}^{I_j}(10-Env+_i)$$

W.214 However, when searching for the SCS and MGA optimal solutions in terms of Environmental benefit, the search algorithm again maximises Environmental benefit within the given cost/ search space constraints.

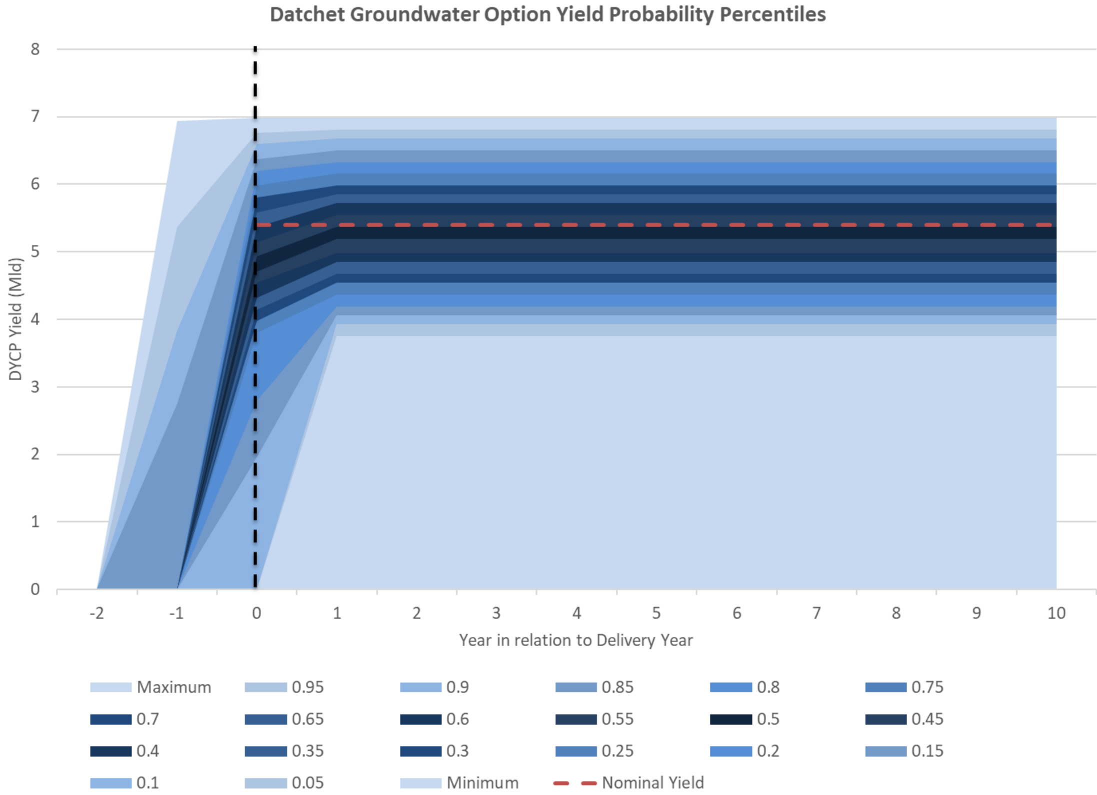
Deliverability

W.215 Programme deliverability is the probability that the programme will deliver sufficient water on time across the planning horizon.

W.216 Programme development based on any metric selects new options to fill any forecast supply-demand gap and ensure there is a surplus in each year of the planning horizon. The capacity of each new option is the most likely deployable output (DO) for the relevant planning scenario (DYAA or DYCP).

W.217 This deterministic DO is taken from a DO profile for each option. Each pdf incorporates the potential impact to yield of lead time uncertainty and final yield uncertainty for the new resource. Figure W-29 shows the probability density function for the DYCP DO of Datchet groundwater option for years prior and post commissioning, with each line representing a probability percentile, and the 50^{th} percentile corresponding to the nominal option DO (5.4 Mld).

Figure W-29: Option nominal capacity with yield uncertainty profile

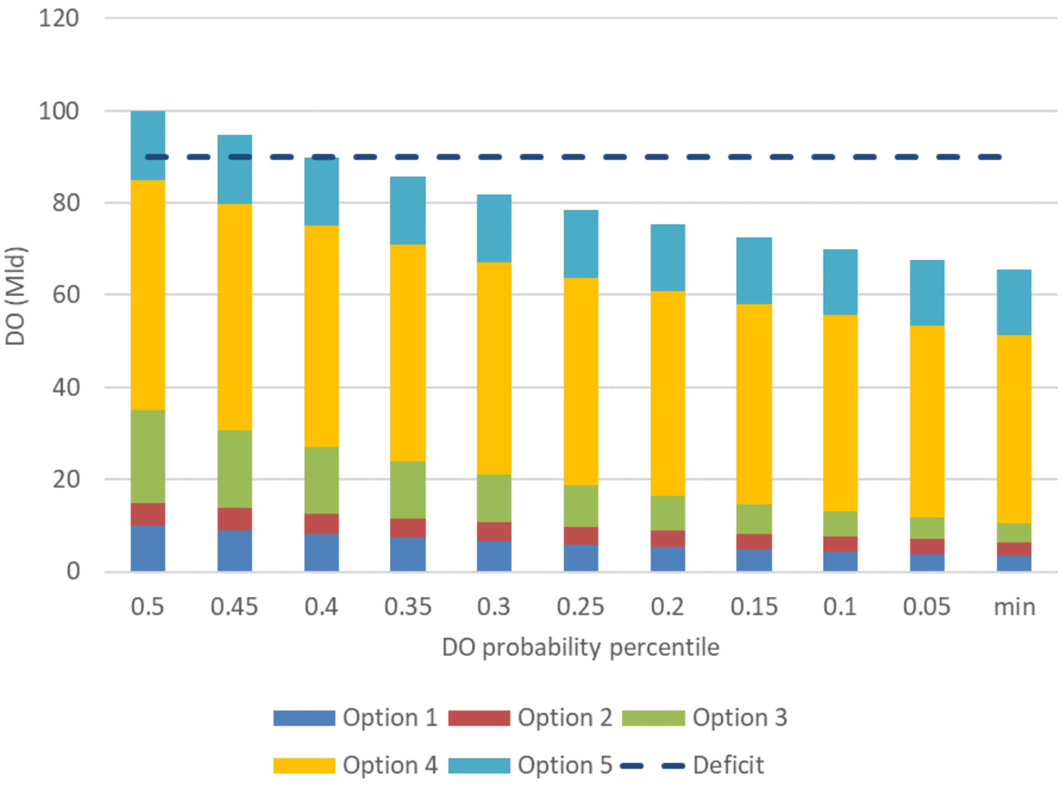


W.218 This means that for each year after new options have been commissioned, there is a probability that the combined new options will not deliver their deterministic yield, and if the difference between deterministic and probabilistic yield is greater than the surplus in that year, then that is the probability that there will be a supply-demand gap.

W.219 There is also a slight probability that the option may be commissioned ahead of schedule.

W.220 In each year for which new options have been selected there is a probability that the new DO will not be sufficient, i.e. the actual DOs achieved will not reach the combined deterministic DO forecast. This probability is calculated as the delivery risk in each year, and Figure W-30 shows an example DO probability profile for a single year for five options combined, together with that year's supply-demand deficit (required DO).

Figure W-30: Example DO probability profile in year y



W.221 The percentile of probable DO available in year y for option i depends on the year in which option i was commissioned (year 0) in relation to year y. In Figure W-30 above, the combined option DOs would fail to meet the deficit at the 40th percentile. The 50th percentile is the most likely (deterministic) DO, and therefore the delivery risk in year y is 10% or 0.1.

W.222 The programme Deliverability:

$$Deliverability_j = 1 - \frac{\sum_{y=1}^{80} Delivery\ Risk_y}{80}$$

Difference between deliverability assessment for the EBSD+ and MCS models

W.223 There is no programme deliverability assessment carried out by the IRAS model.

Resilience

W.224 In order to enable better understanding of relative programme resilience values, the resilience metric was cut down after consultation on the dWRMP and now evaluates only the ability of a proposed investment programme to maintain supply during drought more severe than 1:100 return period.

W.225 The WARMS2 model has evaluated the probable reduction in DO during a range of drought events of different duration and severity for each WRZ[33] (Table W-23).

Table W-23: Supply Surplus required for Drought Resilience

	1:200		1:500	
	DYAA	DYCP	DYAA	DYCP
London	140	140	250	250
SWOX	5.88	6.87	22.4	26.2
SWA	1.86	3.26	3.5	4.5
KV	2.8	3.36	4.1	14.3
Guildford	0	0	0	0
Henley	0	0	0	0

W.226 The figures in Table W-23 reflect the effect of drought on existing resources (baseline WAFU). Drought will also impact the capacity of different types of new option. Effects are calculated from the deterministic DOs given by our Aquator modelling software, WARMS2, and included in the drought resilience assessment.

W.227 Programme resilience is calculated as the probability that the proposed investment programme will not experience level 4 supply failure in the event of a drought, across the planning horizon. The EBSD+ model calculates the probability that any proposed investment programme will maintain sufficient surplus to deliver the required WAFU across the planning period in event of a 1:200 or 1:500 year drought.

$$P_i = \frac{\sum_{y=0}^{80}\{S_y \leq Rq200\}}{80} \cdot \frac{80}{200} + \frac{\sum_{y=0}^{80}\{S_y \leq Rq500\}}{80} \cdot \frac{80}{500}$$

where

Pi is the probability of level 4 failure during a 1:200 or 1:500 drought for programme i

Sy is the supply surplus in year y of the planning horizon

Rq200 is the surplus required to support a 1:200 drought, calculated by WARMS2

Rq500 is the surplus required to support a 1:500 drought, calculated by WARMS2

$$Resilience_i = 1 - P_i$$

W.228 The probable consequence in each year is adjusted by the probability of either drought occurring across the planning period, in order to give a programme resilience score between 1 (no risk of failure during a 1:500 drought in any year), and 0.44 (failure in all years).

[33] Atkins 2018; Thames Water Stochastic Resource Modelling Stage 2&3 Report, Atkins DG04, 16 July 2018

W.229 As the probabilities of 1:200 or 1:500 droughts occurring across the 80 year planning horizon are 0.4 and 0.16 respectively, it is impossible to reach a resilience score of 0.

W.230 Alternative hazards have been considered, but following consultation with the expert panel, in order to enable a metric for which the output can be clearly understood for comparison between different programmes, the resilience hazards used for optimisation have been simplified to one.

W.231 When calculating for several zones simultaneously (London, SWA and SWOX) resilience failure occurs if any zone fails in a year.

W.232 For example in most scenarios we plan to increase drought resilience to 1:200 year droughts by 2030 (see Section E). For each programme developed for this drought resilience, the 'enhanced' resilience output therefore is the risk of insufficient supply should a 1:200 drought occur before 2030, plus the risk should a 1:500 drought occur in any year, and the lowest possible resilience value is 0.79.

W.233 To understand the output values for the preferred scenario programmes, we can assume that very few programmes for London could be resilient to a 1:200 drought before 2030 when the first large options may be commissioned. So the resilience range for the main scenario reduces to between 0.79 and 0.93, with 0.93 meaning that a programme would also be resilient to 1:500 droughts for all 70 years from 2030. Each 0.01 decrease in resilience score indicates reduction of that enhanced 1:500 resilience for five years of the 70.

W.234 In practice, the maximum resilience score is 0.952, the programme optimised to maximise resilience achieves 1:200 resilience at the earliest possible date (2026), and 1:500 resilience in 2029, both of which are maintained to 2100. However, the programme costs £9.2 billion.

Difference between resilience assessment within EBSD+ and MCS models

W.235 The EBSD+ model calculates the number of years a level 4 deficit would occur across the planning horizon should a drought occur in any year, based on a deterministic evaluation of the average surplus requirement for two types of drought.

W.236 However, the IRAS_MCS model assesses performance of an investment portfolio across 153 different 78-year flow scenarios, ranging from wet to 1:500 return period drought and above. As IRAS simulates system performance, in addition to level 4 failure probability, the model can also evaluate how long any deficit may last (recovery), and the probability of different failure levels occurring (level 3). The four resilience outputs from IRAS_MCS are:

- Level 4 Return Period
- Recovery L4 (weeks)
- Level 3 Return Period
- Recovery L3 (weeks)

W.237 The IRAS_MCS simulation results add greater understanding of the significance of a Resilience grade. Work has been carried out to relate the severe drought time-series used to develop programmes in IRAS_MCS to the 1:200 drought hydrological time-series generated by HR Wallingford, thereby clarifying the probability of these failures occurring in alignment with recognised drought frequencies[34].

Intergenerational Equity

W.238 Intergenerational Equity (IGEQ) in water resource planning requires equitable evaluation of the impact of investment on current and future generations. Specific parameters are the Intergenerational Equity of water use (i.e. sustainable leakage and per capita consumption (PCC) reduction) and social impact (i.e. affordable and equitable bill increase for current and future generations).

W.239 Intergenerational Equity ensures that the preferred plan:

- Delivers best value for both present and future generations, in terms of
  - Affordability in the medium to long term
  - Protecting the most vulnerable
- Continues the trend of reducing overall demand via
  - Water efficiency
  - Leakage control

Demand reduction

W.240 Supporting enhanced demand management is a key policy decision from WRMP14 which has continued into the revised draft WRMP19 with enhanced leakage reduction and water efficiency supported through household metering. The demand management programme for each WRZ has been selected to support this policy and is not presented as a choice available to the models (except when SELDM testing). Leakage and PCC reduction are therefore not included in weighting of this metric.

Social impact and intergenerational equity

W.241 The remaining Intergenerational Equity element is equitable affordability for present and future generations.

W.242 Costs are already well defined with each programme NPV calculated using the declining social time preference rate, STPR (Table W-24), as recommended in the WRPGs.

Table W-24: The declining long-term discount rate (Table 6.1; HM Treasury 2003)

Period of Years	0-30	31-75	76-125	126-200	201-300	301+
Discount Rate	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%

[34] HR Wallingford (2018). Drought Libraries for assessing system resilience to droughts, Report MAM8070-RT003-R1-00

W.243 However, the Green Book (HM Treasury 2003) also clearly states that for sensitivity analysis the impact of changing the discount rate can be analysed providing the rationale for undertaking such analysis is clearly explained.

W.244 The discounting of future costs using the STPR is based around the principle that society as a whole prefers to receive goods and services sooner rather than later, and to defer costs to future generations (HM Treasury, 2003). However, recent research has shown that there is a unanimous view across our water customers that costs for major water infrastructure investment should be fairly spread over generations as everyone has benefitted from past investment[35].

W.245 The affordability element of the Intergenerational Equity metric should therefore assess the cost impact of any proposed plan using an Intergenerationally Equitable discount rate, IEDR. Equitable affordability can then be appraised in comparison with the Net Present Value cost developed using the STPR.

Intergenerationally equitable discount rate

W.246 The STPR is a combination of four components:

$$STPR = L + \delta + \mu.g$$

where

L is the catastrophe risk

δ is the Pure Time Preference rate

μ is the elasticity of marginal utility of consumption

g is the expected annual growth in PCC

W.247 Catastrophe risk is the likelihood that there will be an event so devastating that all returns from policies, programmes or projects are eliminated, or at least radically and unpredictably altered. Examples are technological advancements that lead to premature obsolescence, or natural disasters, major wars etc. Newbery[36] estimates L as 1.0, Kula[37] as 1.2, Pearce and Ulph[38] as 1.2, OXERA[39] as 1.1 currently and 1 in the near future. We propose the adoption of lowest rate of 1.0 for sustainable water resources planning, as premature obsolescence of water is not regarded as a risk, although risk of catastrophic population decline remains.

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[35] Thames Water (2016), Long term investment and intergenerational fairness, prepared by Britain Thinks. October

[36] Newbery, D. (1992), *Long term Discount Rates for the Forest Enterprise*, Department of Applied Economics, Cambridge University, for the UK Forestry Commission, Edinburgh

[37] Kula, E. (1987), *Social Interest Rate for Public Sector Appraisal in the United Kingdom, United States and Canada*, Project Appraisal, 2:3, 169–74

[38] Pearce D and Ulph D (1995), *A Social Discount Rate For The United Kingdom*, CSERGE Working Paper No 95-01 School of Environmental Studies University of East Anglia Norwich

[39] OXERA (2002), A Social Time Preference Rate for Use in Long-Term Discounting, Defra.

W.248 Pure time preference reflects individuals' preference for consumption now, rather than later, with an unchanging level of consumption per capita over time. Scott[40] [41] estimates δ as 0.5. Other literature suggests it lies between 0.0 and 0.5. Stern[42] has argued that for ethical reasons the PTP for climate change mitigation investment should be zero; a similar argument could be applied to promote intergenerational equity in water resource planning, and therefore δ = 0 within the IEDR.

W.249 The marginal utility of consumption with respect to utility implies that a marginal increase in consumption will reduce the utility of the product. In terms of water, the first litres of PCC per day are vital for drinking, further consumption for washing and sanitation have high utility, until you reach less high utility such as car washing and filling a paddling pool.

W.250 However, the PCC of water is expected to fall, to enable management of a scarce resource. Part of the investment considered is water efficiency initiatives to encourage reduction in PCC. On the assumption that the lowest sustainable PCC will be attained within the next thirty years with the introduction of universal metering and promotion of water efficiency and leakage reduction, g is advised as zero for a sustainable discount rate for long-term water resource planning, which negates the need for calculation of μ.

W.251 The IEDR for sustainable water resource planning is therefore proposed as 1.0, which is used in place of the STPR to develop the Equitable Affordability element for each programme, used within the Intergenerational Equity metric. Britain Thinks recently reported on inter-generational fairness and understanding how different generations think we should be distributing costs for water investment over time[43]. Customers strongly supported the concept that current generations should be paying for future investment. Their view was that we all use water and therefore should all expect to contribute to the system and that we have all benefitted from past investment and so should expect to do the same for future generations.

W.252 The cumulative NPV for the preferred plan using both the IGEQ 1% and STRP discount rates is presented in Figure W-31 below. Discounting at the lower rate significantly increases the comparative cost of the programme, especially for future generations. Comparative IGEQ and STRP discounted NPVs for all RAPs are present in Appendix X.

Difference between IGEQ assessment for the EBSD+ and MCS models

W.253 There is no intergenerational equity assessment carried out by the IRAS model.

Optimisation using Intergenerational Equity metric

W.254 EBSD+ minimises intergenerational equity (IGEQ) for programme j by minimising the NPV of selected options I_j discounted by the IEDR as defined above.

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[40] Scott, M.F.G. (1977), *The Test Rate of Discount and Changes in Base Level Income in the United Kingdom*, The Economic Journal, 1989 (June) 219-241.

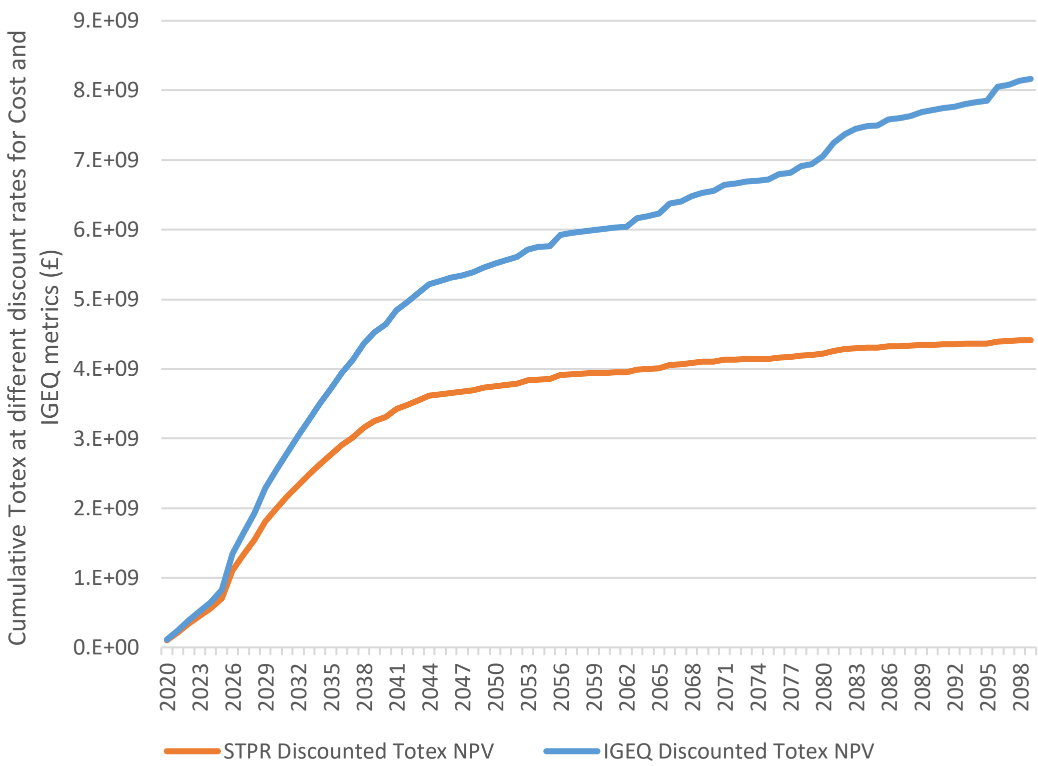
[41] Scott, M.F.G. (1989), *A New View of Economic Growth*, Clarendon Paperbacks

[42] Stern (2007) The Economics of Climate Change, HM Treasury

[43] Based on our programme of ongoing customer research summarised in Appendix T: Our customer priorities and preferences.

$$\text{Minimise} \sum_{y=0}^{80} \left(\frac{1}{(1 + IEDR)^{(y - y_0)}} \right) \sum_{i}^{I_j} (Cost_{i,y})$$

Figure W-31: Effect of discount rate on preferred plan NPV



Customer preference

W.255 Customer research has been carried out as part of a wider analysis for overall business planning purposes. The first stage was qualitative research, enabling customers to better understand business planning and water resource management planning within the wider context of climate and population change, and express their views as to the relative importance of different investment areas.

W.256 The second phase focused more on quantitative assessment of customer preference for specific options or boundary conditions used for WRMP planning, with the result that two separate preference metrics for a plan were calculated using the results of the quantitative assessment, based on two elements:

1) Customer preference for type of option
2) Customer preference for level of service

W.257 A third key element, affordability, was considered, but bill impact calculation depends on additional factors outside the WRMP selection and so bill impact has been assessed for the PR19 Business Plan as a whole and is not included within this metric.

Preference for type of option

W.258 Quantitative customer research has elicited data that indicates preference for one type of water resource option over another (Table W-25).

Table W-25: Customer preference for type of option relative to leakage reduction

Option type	Households	Non-households
Water efficiency campaigns	1.30	0.65
Reducing leakage	1.00	1.00
Transferring treated wastewater at Teddington	0.69	0.20
Reservoir storage with 50% renewable energy	0.46	0.18
Managing land use (catchment management)	0.41	0.19
Water reuse with 20% renewable energy	0.32	0.05
Introducing tariffs	0.26	0.06
Water reuse	0.26	0.00
Desalination with 20% renewable energy	0.18	0.04
Reservoir storage	0.15	0.09
Using groundwater	0.10	0.08
Desalination (removing salt from water)	0.10	0.00
Water transfer	0.10	0.00
Storing water underground	0.09	0.00

W.259 When weighted by the proportion of household and non-household customers, this can be translated to:

Table W-26 Customer support for option types

Option Type	Demand Management	Catchment Management	Reuse	Reservoir	Transfer/ Groundwater/ Desalination	Aquifer Recharge
Support %	100	41	26	15	10	9

W.260 The % preference for each asset type (α) enables calculation of the Type Preference (TP) for any programme from the volume of water available (capacity or demand reduction) from each asset (W).

$$Pref\_T_j = \frac{\sum_i^{I_j} TP_i}{I_j}$$

Preference for level of service

W.261 Customers also gave their views on the acceptable frequency of restrictions to water supply we plan for, such as media campaigns, non-essential use bans, and drought permits and orders (Table W-27).

Table W-27: Level of service

Level of service restriction	Types of intervention	Affects	Restrictions

Level of service restriction	Types of intervention	Affects	Restrictions
Level 1	Media campaign	Customers	Ask for consumer co-operation in reducing water use
Level 2	Sprinkler and unattended hosepipe ban	Customers	No using a sprinkler or unattended hosepipe
Level 3	Temporary Use Ban and Drought Permit and Ordinary Drought Order	Environment, and customers	Full hosepipe ban. Permit (from Environment Agency) to take water from sources specified for drought only or to modify or suspend limits on an existing abstraction licence Order (From Secretary of State) to restrict business use and increase water supplies
Level 4	Emergency Drought Order	Environment and customers	Restrictions on supply, alternative sources such as a standpipe in the street

W.262 A key level of service underpinning the definition of the water resource planning problem is the acceptable frequency at which level 4 restrictions would occur. Previously the supply-demand problem has been based on ensuring sufficient capacity to withstand the worst historic drought on record without requiring level 4 restrictions, which would occur approximately once in every one hundred years.

W.263 For this revised draft WRMP19, stochastically derived drought libraries have been developed which allow assessment of more severe droughts than the worst on record and allow better understanding of the supply required to withstand extreme droughts which typically occur only once in 200, 300 or 500 years.

W.264 Customer views have been sought on how desirable it is to plan for these more extreme droughts. The research findings (Table W-28) have been used in the Preference metric to promote an acceptable level of drought resilience within the revised draft WRMP19.

Table W-28: Customer preference for Level 4 restriction frequency - London

Level 4 restriction	1:100	1:200	1:300	1:500
Preference %	88.3	10.4	0.8	0.5
Additional capacity required (Mld)	0	140	177	250

W.265 Simulation modelling has estimated the supply available over a range of stochastic droughts, and the outputs have been used to set thresholds for the additional standby capacity (SC) required to meet demand without Level 4 restrictions during droughts of increasing severity.

W.266 The % preference for each restriction frequency (FP) for drought frequency λ is allocated as the Frequency Preference (FP) for any programme from the standby capacity available by 2044/45 (minimum statutory planning period).

$$Pref\_F_j = \frac{\sum_{y=0}^{2044/45} FP_\lambda \frac{DOsurplus_{j,y}}{|DOrequired_\lambda|}}{25}$$

W.267 Optimisation of a summation of two independent components in the Preference metric is computationally challenging. Preference is therefore optimised for both elements separately, increasing the number of programmes available for assessment.

$$Pref\_T_j = \min_{\vec{o}} \left\{ \sum_{i}^{I_j} (1 - TP_i) \right\}$$

$$Pref\_F_j = \min_{\vec{o}} \left\{ \sum_{y=0}^{2044/45} FP_\lambda \frac{DOsurplus_{j,y}}{|DOrequired_\lambda|} \right\}$$

W.268 The Preference score for any programme is the sum of both components.

Difference between preference assessment for the EBSD+ and MCS models

W.269 Adaptability is assessed using the EBSD+ model only, although the programmes shortlisted for further testing may have been selected from those generated by either model in the first instance.

Conclusions

W.270 The WRPG presents clear guidance for water companies to move from least cost development of WRMPs towards a *best value* plan for revised draft WRMP19, taking into account several additional metrics beyond financial cost.

W.271 We have developed a set of models for programme appraisal for revised draft WRMP19 that are able to optimise on single criteria other than least cost and also multiple criteria optimisation. The metrics chosen are: Cost; Environmental Benefit; Adverse Environmental Impact; Deliverability; Resilience; Intergenerational Equity; Preference and Adaptability.

W.272 This Appendix has explained how the metrics have been reviewed and defined.

Programme appraisal and selection of preferred plan

W.273 Multiple programmes or portfolios of investment have been generated by EBSD+ and IRAS_MCS respectively, for comparative assessment and shortlisting of leading programmes/ portfolios.

W.274 Shortlisted EBSD+ programmes undergo a plan-level SEA to evaluate the combined environmental impact of all the options in each, and Adaptability analysis to test how well they could adjust to a wide range of better or worse futures. Shortlisted IRAS_MCS portfolios are re-optimised to schedule investment across the planning horizon.

W.275 Combining all the outputs from the different analyses, programme appraisal is carried out to select a preferred plan, as described in Section 10 and Appendix X.

W.276 Further sensitivity testing is carried out on the preferred plan to assess the individual impact of a wide range of potential different futures, What-if testing.

Symbols

Capex	capital expenditure
Carb	Carbon
CostUnc	cost uncertainty
DeficitDO	deficit in DO
Delv	deliverability
DO	deployable output
EnvAdv	adverse environmental impact
EnvBen	environmental benefit
EquAff	equitable affordability
FOpex	fixed annual operational expenditure
FP_j	Preference for level of service in programme j
g	expected annual growth in PCC
h	hazard
H	total number of hazards
i	option
I_j	Total number of options in programme j
IEDR	intergenerationally equitable discount rate
j	potential programme
L	catastrophe risk
LeadUnc	works duration uncertainty
Lkg	leakage
p	adaptability pathway
P	total number of adaptability pathways
PCC	per capita consumption
rq	total requested water trading
SDBfailure	supply demand balance failure
SDG	supply demand gap
STPR	social time preference rate

SurplusDO	surplus deployable output
TP_j	Preference for options types in programme j
Util	utilisation
VOpex	variable operational expenditure per Mld
y	year
y0	initial year
y80	final year of 80 year planning horizon
YieldUnc	benefit uncertainty
δ	pure time preference rate
µ	elasticity of marginal utility of consumption

Annex 1: Problem characterisation worksheet

PROBLEM CHARACTERISATION

London WRZ

1. How big is the problem?

Table 1: Assessment of the strategic needs for WRMP purposes	**No significant concerns (Score = 0)**	**Moderately significant concerns (Score = 1)**	**Very significant concerns (Score = 2)**
Scale of significance		*Is there a sustained deficit caused by a combination of changes in both the supply and demand elements.*	*Could either element cause a sustained deficit by itself, or in combination, presenting a change in the level of service to customers or risk of system failure restrictions i.e. water restrictions such as a rota cut*
TW: Are there current or future risks to available resources which could affect water supply to customers? UKWIR: Level of concern that customer service could be significantly affected by current or future **supply side risks**, without investment.			We identified a significant resource deficit in London driven by climate change in WRMP14 growing from 31 Mld in 2015 to 77.6 Mld by 2035; allowing for uncertainty this further increases to 140 Mld by 2040. There were further unknown sustainability reductions of 174 Mld. For revised draft WRMP19 we anticipate that the resource deficit will increase due to better understanding of the analysis of historic droughts, the impacts of achieving WFD objectives and potential impacts of climate

			change on resources.
TW: Are there current or future risks to forecast demand which could affect water supply to customers? UKWIR: Level of concern that customer service could be significantly affected by current or future **demand side risks**, without investment			In WRMP14 we forecast an ongoing increase in population in our area of between 2.0 million and 2.9 million people by 2040 – three quarters of which was forecast in London, equivalent to over 300 Mld. Since publication of WRMP14 the Greater London Authority (GLA) published revised forecasts showing an increase in population in London of ~2.5m by 2050.
Scale of significance		*Concerns raised around the level of cost or contentious option in terms of environmental/planning risks.*	*Investment programme that has components that are potentially controversial with costs that large enough to have a material impact on customer bills.*
TW: Is it likely that the investment programme will include some options which are contentious? Will the investment programme likely to have a significant impact on customers' bills? UKWIR: Level of concern over the acceptability of the cost of the likely investment programme, and/or that the likely investment programme contains contentious options			The supply demand deficit forecast in WRMP14 will require the implementation of extensive demand management over the period to 2025, and development of new resources in the medium to long term. Work is in progress to examine a range of options including reservoirs, raw water transfers, desalination and reuse. Each of these large options has advantages and disadvantages and are likely to be controversial. Furthermore the costs of large scale investment will affect customers' bills.

(including environmental/planning risks)			

2. How difficult is the problem to solve?

Assessment of supply side complexity for WRMP purposes

Supply side complexity factors	**No significant concerns (Score = 0)**	**Moderately significant concerns (Score = 1)**	**Very significant concerns (Score = 2)**
Scale of significance		*Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings*	*Factor generates uncertainty in the overall nature of the investment programme and/or could cause conflict with stakeholders/regulators*
TW: Are there concerns about the reliability of available resources in the short term and concerns beyond historical record? UKWIR: Are there concerns about **near term** supply system performance either because of recent level of service failures or because of poor understanding of system reliability/resilience under different or more severe droughts than those contained			The extended drought of 2011/12 demonstrated that the supply system in London is currently vulnerable to a severe drought worse than those which have occurred in the period 1920 - 2015. The wettest spring and summer period on record occurring in 2012 avoided the need for severe water use restrictions and environmentally damaging drought permits but London remains vulnerable to a severe drought. Our draft Drought Plan (2016) demonstrates that in the short term to 2022, security of supply could be maintained in events with recurrence intervals of 1 in 300 and 1 in 500 frequency. However, this requires drought permits to be operational for nine months and no operational

in the historic record? Is this exacerbated by uncertainties about the benefits of optional interventions contained in the Drought Plan?			outage of our major drought assets. Ongoing population growth and the impacts of climate change in the long-term indicate that London is not robust to such events in the medium and long term.
TW: Are there concerns about the performance of the system in the future associated with the impacts of climate change and associated water quality issues? UKWIR: Are there concerns about future supply system performance, primarily due to uncertain impacts of climate change on vulnerable supply systems, including associated source deterioration (water quality, catchments) or poor understanding			Sensitivity testing completed on the preferred programme (Beckton reuse plant) for WRMP14 (Section 10: Programme appraisal and scenario testing) showed that the system would fail (level 4 restrictions required) under more severe droughts forecast to occur under climate change using the Future Flows and Groundwater Levels data (Centre for Ecology and Hydrology Natural Environment Research Council (2012) Future Flows and Groundwater Levels: British projections for the 21st century). The preferred programme proposed in WRMP14 highlighted that the Plan in London is sensitive to any moderate to large reductions in water available for use in the future – for example, due to unknown sustainability reductions, delivering WFD objectives or higher than expected impacts of climate change – and requires additional resource schemes to address this risk.

TW: Are there potential stepped changes in the available resources in the near to medium term i.e. over the next 10 years? UKWIR: Are there concerns about the potential for "stepped" changes in supply (e.g. sustainability reductions, bulk imports etc.) in the near or medium term that are currently uncertain?			For WRMP14 174 Mld of unknown sustainability reductions were highlighted in London. Studies are currently ongoing in AMP6 to investigate these issues and understand the need for changes in abstraction. Any reductions in abstraction are expected to be implemented over the period to 2030. There is also review underway, led by the Environment Agency, to understand the potential of serious damage and risk of no deterioration linked to WFD objectives which could drive further changes of up to 50 Mld.
TW: Is the reliability of the available resources of a new supply option linked to other schemes and factors beyond the company's immediate direct control? UKWIR: Are there concerns that "DO" metric might fail to reflect resilience aspects that influence the choice of investment options (e.g. duration of failure), or are their conjunctive dependencies between new options (i.e. the amount of benefit from one option depends on the			Work is underway to examine the resilience of future supply options. Transfers of raw water from other companies and other catchments is dependent on the water being available when it is needed, for example would a potential drought affect catchments simultaneously. Analysis of the spatial coherence of droughts has indicated that a severe drought in the south east (1 in 500 occurrence) could be coincidental with a 1 in 300 year drought in the River Severn catchment, limiting water availability for transfer. The release of water for a Severn Thames Transfer depends on the development of new water resources by both United Utilities and Severn Trent. Also is the quality of the water satisfactory? For example in 2015 issues with levels of metaldehyde in the Ely Ouse

construction of another option). These can both be considered as non-linear problems.			transfer scheme restricted raw water transfer from Essex and Suffolk to Thames Water (Abberton scheme). For reuse a concern is the potential for an incident of contamination which may affect the source. For example NE London 2-EDD and 2-EMD taste and odour incident in 2010 impacted raw water transfer to Essex and Suffolk Water. The resilience of a new reservoir in the Thames catchment could be improved through the transfer of raw water from another catchment. Reductions in customer water use are dependent on behavioural changes in water consumption and such control is outside our immediate direct control.

Assessment of demand side complexity for WRMP purposes

Demand side complexity factors	**No significant concerns (Score = 0)**	**Moderately significant concerns (Score = 1)**	**Very significant concerns (Score = 2)**
		Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings	*Factor generates uncertainty in the overall nature of the programme and/or could cause conflict with stakeholders/regulators*
TW: Are there concerns about changes in the demand for water in the short term? UKWIR: Are there concerns about changes in current or near term demand e.g. in terms of demand profile, total demand, or changes in economics/demographics or customer characteristics			In 2014 the GLA published revised population and property projections in the London Plan which are significantly higher than the previous forecast included in our WRMP14, published in August 2014. The population could be as much as 700 000 higher in 2040. Our WRMP14 includes substantial savings from demand management dependent on customers changing their water use behaviour and as such is not directly controllable by Thames Water. The Preferred Plan has savings in London over the period to 2025 equating to 197 Mld, delivering more than 70% of the total water required (277 Mld) in the short/medium term to maintain security of supply. As such it is a high risk programme, vulnerable to changes in population growth and customer behaviour.

TW: Is the uncertainty over forecasts of population and property sufficient to change the investment? UKWIR: Does uncertainty associated with forecasts of demographic/ economic/ behavioural changes over the planning period cause concerns over the level of investment that may be required.			There is uncertainty in population and property forecasts. GLA produced scenarios which reflects the uncertainty in the forecasts. The range between the most conservative and most optimistic forecasts is 3.9 million people, which is equivalent to around 600 Mld of water required.
TW: Is demand sensitive to, and varies significantly, during periods of drought? UKWIR: Are there concerns that a simple "dry year/normal year" assessment of demand is not adequate e.g. because of high sensitivity to demand to drought (so demand under severe events needs to be understood) or because demand versus drought timing is critical		For planning purposes we assume that customers will reduce their water demand during periods of drought. Potential maximum cumulative savings for L1-L3 restrictions in London based on 2005/6 data is 14.5%. (Thames Water Drought Plan 2013). However we anticipate the potential for savings will change as a result of progressive household metering and non-household competition. As such, reliance on historical water use patterns in the future is high risk and has potential to change the investment programme.	

Assessment of the investment programme complexity for WRMP purposes

Investment Programme Complexity Factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
		Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings	*Factor generates uncertainty in the overall nature of the programme and/or could cause conflict with stakeholders/regulators*
TW: Does the amount of uncertainty in capital expenditure affect the decision on the investment programme? UKWIR: Are there concerns that capex uncertainty (particular in relation to new or untested methodologies) could compromise the company's ability to select a best value portfolio over the planning period?			The innovative nature of many of the water resource schemes that we are examining (wastewater reuse, raw water transfers, desalination) inevitably mean that there will be significant uncertainty associated with cost estimates. For example, our estimates of the costs for the Beckton desalination plant in 2004 were significantly lower than have been experienced in reality, where the ongoing maintenance costs incurred have been much higher than originally anticipated. Also mitigation potentially required for raw water transfers could be significant, for example management of water quality and sediment issues.

TW: Do factors such as lead time and promotability affect the decision on the programme? UKWIR: Does the nature of feasible options mean that construction lead time or scheme promotability are a major driver of the choice of investment portfolio?			These are factors that are considered as part of the programme appraisal and development and are important considerations alongside other parameters. There is significant difference in the lead time of schemes and experience has demonstrated that lengthy planning inquiries are often associated with the promotion of large new water resource schemes. The Beckton desalination plant was included in our WRMP04 but construction was not completed until 2010 because a public inquiry was required to secure planning permission. 15 years is the assumed lead time for promotion and construction of a reservoir. It can therefore be assumed that major resource schemes will require between 5 - 15 years before lead time before increased water resources are available.
TW: Can wider considerations that are non monetisable be properly considered in decision making? UKWIR: Are there concerns that trade-offs between costs and non-monetised "best value" considerations (social, environment) are so complex that they required quantified analysis (beyond SEA) to		There are several factors that need to be considered in developing the best value plan. In addition to financial costs, robust assessment of non-monetised considerations is important. This will involve qualitative and quantitative assessment and it is vital that these assessments are clear and understandable to stakeholders. We are developing a number of metrics to facilitate programme appraisal and development of a best value	

justify final investment decisions.		investment programme. The metrics include cost, adaptability, sustainability, environmental effects, resilience, deliverability and customer acceptability.	
TW: Is the investment programme sensitive to assumptions about the utilisation of new resources? UKWIR: Is the investment programme sensitive to assumptions about the utilisation of new resources, mainly because of large differences in variable opex between investment options?			The utilisation of resource options is a very important consideration in the assessment of options. The resource scheme will be primarily required to support supply during a dry year and as such would not normally be used in a normal year. However, underlying ongoing growth in demand throughout the forecast period and the increasing impacts of climate change on water available for use mean that the base level utilisation of the new resource will change throughout the forecast period.

SWOX WRZ

1. How big is the problem?

Table 1: Assessment of the strategic needs for WRMP purposes	**No significant concerns (Score = 0)**	**Moderately significant concerns (Score = 1)**	**Very significant concerns (Score = 2)**
Scale of significance		*Is there a sustained deficit caused by a combination of changes in both the supply and demand elements.*	*Could either element cause a sustained deficit by itself, or in combination, presenting a change in the level of service to customers or risk of system failure restrictions i.e. water restrictions such as a rota cut*
TW: Are there current or future risks to available resources which could affect water supply to customers? UKWIR: Level of concern that customer service could be significantly affected by current or future **supply side risks**, without investment.		In WRMP14 we identified loss of DO in SWOX driven by climate change, growing from 2.7 Mld in 2015 to 13.9 Mld by 2040. For revised draft WRMP19 we anticipate that the resource deficit will increase due to better understanding of the analysis of historic droughts, the impacts of achieving WFD objectives and potential impacts of climate change on resources.	

TW: Are there current or future risks to forecast demand which could affect water supply to customers? UKWIR: Level of concern that customer service could be significantly affected by current or future **demand side risks**, without investment			In WRMP14 we forecast an ongoing increase in population of approximately 0.15 million people by 2040 in SWOX, equivalent to almost 20 Mld household consumption (average PCC of 125 l/h/d 2040), or 7% of total demand. Since publication of WRMP14 revised household forecasts in response to direction from Government have shown a further increase in population is expected.
Scale of significance		*Concerns raised around the level of cost or contentious option in terms of environmental/planning risks.*	*Investment programme that has components that are potentially controversial with costs that large enough to have a material impact on customer bills.*

TW: Is it likely that the investment programme will include some options which are contentious? Will the investment programme likely to have a significant impact on customers' bills? UKWIR: Level of concern over the acceptability of the cost of the likely investment programme, and/or that the likely investment programme contains contentious options (including environmental/planning risks)			The supply demand deficit forecast in WRMP14 will require the implementation of extensive demand management over the period to 2020 - 2030, and development of new resources in the medium to long term. Work is in progress to examine a range of options which could supply both London and SWOX employing reservoirs or raw water transfers as there is little potential for significant development of groundwater resources to meet the forecast deficit in the supply demand balance. Both of these types of large option have advantages and disadvantages and are likely to be controversial, furthermore the costs of large scale investment will affect customers' bills. The roll out of progressive metering, tariffs and water efficiency provides customers with opportunity to reduce household bills, although where metering causes affordability issues we have special tariffs to help with this.

2. How difficult is the problem to solve?

Assessment of supply side complexity for WRMP purposes

Supply side complexity factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
Scale of significance		*Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings*	*Factor generates uncertainty in the overall nature of the investment programme and/or could cause conflict with stakeholders/regulators*
TW: Are there concerns about the reliability of available resources in the short term and concerns beyond historical record. UKWIR: Are there concerns about **near term** supply system performance either because of recent level of service failures or because of poor understanding of system reliability/resilience under different or more severe droughts than those contained in the historic record? Is this exacerbated by uncertainties about the benefits of optional interventions contained in the Drought Plan?		Seven Springs source proved to be insufficiently resilient to peak demand conditions in 2013 and additional connectivity is being provided. This highlighted that there may be areas within SWOX WRZ which are not fully resilient to extreme weather patterns, especially droughts more severe than those in historical record. Our draft Drought Plan (2016) demonstrates that in the short term to 2022, security of supply could be maintained in events with recurrence intervals of 1 in 300 and 1 in 500 frequency. However, this requires drought permits to be operational for 9 months. Ongoing population growth and the impacts of climate change in the long-term indicate that SWOX is not robust to such events in the long	

		term.	
TW: Are there concerns about the performance of the system in the future? UKWIR: Are there concerns about future supply system performance, primarily due to uncertain impacts of climate change on vulnerable supply systems, including associated source deterioration (water quality, catchments) or poor understanding			At the extremities of the zone there remain areas with isolated networks i.e. they are not connected into the wider distribution network, which make up 1.2% of the connected properties. These areas are often rural and have needed relatively little investment to balance supply and demand. However, despite emergency measures in place they are more vulnerable to source deterioration than the interconnected areas of the zone. In WRMP14 we identified loss of DO in SWOX driven by climate change, growing from 2.7 Mld in 2015 to 13.9 Mld by 2040. This vulnerability to the effects of climate change will increase in the long term given the significance reliance of the zone on surface water abstraction from the River Thames at Farmoor to supply the large urban areas of Oxford, Swindon and Banbury. Farmoor reservoir is heavily committed and decreasing summer rainfall volumes forecast under climate change will increase reliance on Farmoor reservoir. Changing water quality patterns and algal blooms associated with climate change are also expected to increase outages at the site.

TW: Are there potential stepped changes in the available resources in the short to midterm? UKWIR: Are there concerns about the potential for "stepped" changes in supply (e.g. sustainability reductions, bulk imports etc.) in the near or medium term that are currently uncertain?		For WRMP14 13.2 Mld of sustainability reductions were included in the plan for SWOX. There is also review underway, led by the Environment Agency, to understand the potential of serious damage and risk of no deterioration linked to WFD objectives which could drive further changes, but these have not yet been identified.	

TW: Is the reliability of the available resources affected by other factors? UKWIR: Are there concerns that "DO" metric might fail to reflect resilience aspects that influence the choice of investment options (e.g. duration of failure), or are their conjunctive dependencies between new options (i.e. the amount of benefit from one option depends on the construction of another option). These can both be considered as non-linear problems.			Work is underway to examine the resilience of future supply options which may supply SWOX simultaneously. Transfers of raw water from other companies and other catchments is dependent on the water being available when it is needed, for example would a potential drought affect catchments simultaneously. Analysis of the spatial coherence of droughts has indicated that a severe drought in the south east (1 in 500 occurrence) could be coincidental with a 1 in 300 year drought in the River Severn catchment, limiting water availability for transfer. Also is the quality of the water satisfactory? For example in 2015 issues with levels of metaldehyde in the Ely Ouse transfer scheme restricted raw water transfer from Essex and Suffolk to Thames Water (Abberton scheme).

Assessment of demand side complexity for WRMP purposes

Demand side complexity factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
		Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings	*Factor generates uncertainty in the overall nature of the programme and/or could cause conflict with stakeholders/regulators*

TW: Are there concerns about changes in the demand for water in the short term? UKWIR: Are there concerns about changes in current or near term demand e.g. in terms of demand profile, total demand, or changes in economics/demographics or customer characteristics		In 2014 the GLA published revised population and property projections in the London Plan which are significantly higher than the previous forecast included in our WRMP14, published in August 2014. The population could be as much as 700 000 higher in 2040, and migration to commuter areas such as Swindon, Didcot, Oxford or Banbury is a likely transferred effect of the increase in the capital. Oxford Parkway railway station was opened in 2015 providing an additional railway link to London. In addition there is significant growth planned in Oxfordshire as set out in the Strategic Housing Market Assessment for Oxon. Government has instructed Oxfordshire County Council to increase the provision of new households beyond what was previously included in local housing plans. Our WRMP14 includes substantial savings from demand management dependent on customers changing their water use behaviour and as such is not directly controllable by Thames Water. The Preferred Plan has savings in SWOX over the period to 2030 equating to 20.9 Mld,	

		delivering 98% of the total water required (21.3 Mld) in the medium term to maintain security of supply. As such it is a medium risk programme, vulnerable to changes in population growth and customer behaviour.	
TW: Is the uncertainty over forecasts of population and property sufficient to change the investment? UKWIR: Does uncertainty associated with forecasts of demographic/ economic/ behavioural changes over the planning period cause concerns over the level of investment that may be required.		There is uncertainty in population and property forecasts, as evidenced by the Strategic Housing Market Assessment for Oxfordshire. There is significant variation in the mid-point local plan and SHMA housing projections for local districts in Oxfordshire. Environment Agency data shows that from 2001-2011 Oxford city's population grew on average by 1766 per year. With occupancy of 2.35 that would equate to 751 homes per year, i.e. between the Council's Oxford city and SHMA Oxford city projections of 400 and 1400, respectively. GLA produced scenarios which reflects the uncertainty in forecasts in the capital. The range between the most conservative and most optimistic forecasts is 3.9 million people, which is equivalent to around 600 Mld of water required. This has a potential	

		transferred affect to SWOX due to increased migration from London. As the housing market in the capital becomes more congested populations often move out to surrounding areas and commute into London. Oxford, Swindon, Didcot Parkway, Bicester and Banbury are all commuter towns with good rail links to London.	
TW: Is demand sensitive to, and varies significantly, during periods of drought? UKWIR: Are there concerns that a simple "dry year/normal year" assessment of demand is not adequate e.g. because of high sensitivity to demand to drought (so demand under severe events needs to be understood) or because demand versus drought timing is critical		For planning purposes we assume that customers will reduce their water demand during periods of drought. Potential maximum cumulative savings for L1-L3 restrictions in the Thames Valley based on 2005/6 data is 19.1%. (Thames Water Drought Plan 2013). However we anticipate the potential for savings will change as a result of progressive household metering and non-household competition. As such, reliance on historical water use patterns in the future is medium risk.	

Assessment of the investment programme complexity for WRMP purposes

Investment Programme Complexity Factors	**No significant concerns (Score = 0)**	**Moderately significant concerns (Score = 1)**	**Very significant concerns (Score = 2)**
Scale of significance		*Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings*	*Uncertainty in the overall nature of the programme and/or cause conflict with stakeholders*
		Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings	*Factor generates uncertainty in the overall nature of the programme and/or could cause conflict with stakeholders/regulators*
TW: Does the amount of uncertainty in capital expenditure affect the decision on the investment programme? UKWIR: Are there concerns that capex uncertainty (particular in relation to new or untested methodologies) could compromise the company's ability to select a best value portfolio over the planning period?			The nature of the strategic water resource schemes which may serve SWOX (raw water transfer, reservoir) inevitably means that there will be significant uncertainty associated with cost estimates. For example, potential mitigation required for raw water transfers, to manage water quality and sediment issues, could be significant.

TW: Do factors such as lead time and promotability affect the decision on the programme? UKWIR: Does the nature of feasible options mean that construction lead time or scheme promoability are a major driver of the choice of investment portfolio?			These are factors that are considered as part of the programme appraisal and development and are important considerations alongside other parameters. There is significant difference in the lead time of schemes and experience has demonstrated that lengthy planning inquiries are often associated with the promotion of large new water resource schemes.
TW: Can wider considerations that are non monetisable be properly considered in decision making? UKWIR: Are there concerns that trade-offs between costs and non-monetised "best value" considerations (social, environment) are so complex that they required quantified analysis (beyond SEA) to justify final investment decisions.		There are several factors that need to be considered in developing the best value plan. In addition to financial costs, robust assessment of non-monetised considerations is important. This will involve qualitative and quantitative assessment and it is vital that these assessments are clear and understandable to stakeholders. We are developing a number of metrics to facilitate programme appraisal and development of a best value investment programme. The metrics include cost, adaptability, sustainability, environmental effects, resilience, deliverability and customer acceptability.	

TW: Is the investment programme sensitive to assumptions about the utilisation of new resources? UKWIR: Is the investment programme sensitive to assumptions about the utilisation of new resources, mainly because of large differences in variable opex between investment options?		SWOX is currently 60% supplied by groundwater, and has sufficient small groundwater schemes to maintain supply for a significant period, possibly 50 years. However, if a strategic resource option were selected to also supply SWOX, utilisation of the new asset would be a key concern.	

SWA WRZ

1. How big is the problem?

Table 1: Assessment of the strategic needs for WRMP purposes	**No significant concerns (Score = 0)**	**Moderately significant concerns (Score = 1)**	**Very significant concerns (Score = 2)**
Scale of significance		*Is there a sustained deficit caused by a combination of changes in both the supply and demand elements.*	*Could either element cause a sustained deficit by itself, or in combination, presenting a change in the level of service to customers or risk of system failure restrictions i.e. water restrictions such as a rota cut*
TW: Are there current or future risks to available resources which could affect water supply to customers? UKWIR: Level of concern that customer service could be significantly affected by current or future **supply side risks**, without investment.		In WRMP14 we identified a small resource deficit in SWA driven primarily by climate change. Allowing for uncertainty, the impacts of climate change in reducing available resources are forecast to grow from 2.3 Mld of the 191 Mld of water available for use in 2020 to 4.6 Mld by 2040. For revised draft WRMP19 we anticipate that the resource deficit could increase due to the impacts of achieving WFD objectives.	
TW: Are there current or future risks to forecast demand which could affect water supply to customers?			We forecast an ongoing increase in population of approximately 127 847 people by 2045 in SWA, equivalent to approximately 19 Mld, or 11% of baseline demand in 2019. The total forecast increase in population to 2099 is 1 024

UKWIR: Level of concern that customer service could be significantly affected by current or future **demand side risks**, without investment			560. There is also a proposed WRSE regional transfer export of 10 Mld to South East Water (Surrey Hills) from 2030.
Scale of significance		*Concerns raised around the level of cost or contentious option in terms of environmental/planning risks.*	*Investment programme that has components that are potentially controversial with costs that large enough to have a material impact on customer bills.*
TW: Is it likely that the investment programme will include some options which are contentious? Will the investment programme likely to have a significant impact on customers' bills? UKWIR: Level of concern over the acceptability of the cost of the likely investment programme, and/or that the likely investment programme contains contentious options (including environmental/planning risks)			SWA has unused small schemes available totalling approximately 8 Mld, which could potentially provide new resources to address the baseline supply demand deficit for up to 2040. There is also extensive demand management planned over the period to 2020 - 2030, which could further reduce the supply demand deficit. To address the long-term deficit (2050s), additional supply will be required from potentially contentious, high cost options in the neighbouring SWOX WRZ.

2. How difficult is the problem to solve?

Assessment of supply side complexity for WRMP purposes

Supply side complexity factors	**No significant concerns (Score = 0)**	**Moderately significant concerns (Score = 1)**	**Very significant concerns (Score = 2)**
Scale of significance		*Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings*	*Factor generates uncertainty in the overall nature of the investment programme and/or could cause conflict with stakeholders/regulators*
TW: Are there concerns about the reliability of available resources in the short term and concerns beyond historical record. UKWIR: Are there concerns about **near term** supply system performance either because of recent level of service failures or because of poor understanding of system reliability/resilience under different or more severe droughts than those contained in the historic record? Is this exacerbated by uncertainties about the benefits of optional interventions contained in the Drought Plan?	SWA WRZ has a fully integrated network supplied 100% by groundwater, which has historically remained robust during drought, the critical point at which source outputs decline below their DO having never been reached. There are no near-term performance concerns expected even for drought beyond historical record.		

TW: Are there concerns about the performance of the system in the future? UKWIR: Are there concerns about future supply system performance, primarily due to uncertain impacts of climate change on vulnerable supply systems, including associated source deterioration (water quality, catchments) or poor understanding	SWA WRZ uses 100% groundwater, mainly from Thames-side sources in the south of the zone which are pumped north. Groundwater sources tend to be less vulnerable to catchment pollution, and the level of integration of the network means there is little likelihood of areas within the zone being vulnerable due to point pollution incidents.		
TW: Are there potential stepped changes in the available resources in the short to midterm? UKWIR: Are there concerns about the potential for "stepped" changes in supply (e.g. sustainability reductions, bulk imports etc.) in the near or medium term that are currently uncertain?		In SWA WRZ a 6.5 Mld reduction in DO has been identified due to a sustainability reduction at Hawridge, ~3% of total WAFU.	
TW: Is the reliability of the available resources affected by other factors? UKWIR: Are there concerns that		New sources are likely to be groundwater schemes for the near and medium-term future, which are unlikely to be contentious and likely to be highly resilient. The volumes available are	

"DO" metric might fail to reflect resilience aspects that influence the choice of investment options (e.g. duration of failure), or are their conjunctive dependencies between new options (i.e. the amount of benefit from one option depends on the construction of another option). These can both be considered as non-linear problems.		approximately 9 Mld. Given the ongoing high population forecast in the zone the need for alternative sources (surface water from the Thames, intra zonal water transfer from SWOX WRZ, for example) is likely to arise in the long-term future.	

Assessment of demand side complexity for WRMP purposes

Demand side complexity factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
		Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings	*Factor generates uncertainty in the overall nature of the programme and/or could cause conflict with stakeholders/regulators*
TW: Are there concerns about changes in the demand for water in the short term? UKWIR: Are there concerns about changes in current or near term demand e.g. in terms of demand profile, total		Our WRMP14 includes substantial savings from demand management dependent on customers changing their water use behaviour and as such is not directly controllable by Thames Water. The Preferred Plan has savings in SWA over the period to 2030 equating to 10 Mld, without which the zone may require	

demand, or changes in economics/demographics or customer characteristics		additional resource by 2030 to support the proposed 10 Mld WRSE export to South East Water if security of supply is to be maintained. As such it is a medium risk programme, vulnerable to changes in population growth and customer behaviour.	
TW: Is the uncertainty over forecasts of population and property sufficient to change the investment? UKWIR: Does uncertainty associated with forecasts of demographic/ economic/ behavioural changes over the planning period cause concerns over the level of investment that may be required.		There is uncertainty in population and property forecasts. GLA produced scenarios which reflects the uncertainty in the forecasts. The range between the most conservative and most optimistic forecasts is 3.9 million people, which is equivalent to around 600 Mld of water required. This has a potential transferred affect to SWA due to increased migration from London. The range in population in SWA at 2045 is 592 454 (5%ile) to 754 501 (95%ile) which equates to a population of 162 047 and with a consumption of 130 l/h/d would be 22 Mld.	
TW: Is demand sensitive to, and varies significantly, during periods of drought? UKWIR: Are there concerns that a simple "dry year/normal		For planning purposes we assume that customers will reduce their water demand during periods of drought. Potential maximum cumulative savings for L1-L3 restrictions in the Thames Valley based on 2005/6 data	

year" assessment of demand is not adequate e.g. because of high sensitivity to demand to drought (so demand under severe events needs to be understood) or because demand versus drought timing is critical		is 19.1%. (Thames Water Drought Plan 2013). However we anticipate the potential for savings will change as a result of progressive household metering and non-household competition. As such, reliance on historical water use patterns in the future is medium risk.	

Assessment of the investment programme complexity for WRMP purposes

Investment Programme Complexity Factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
Scale of significance		*Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings*	*Uncertainty in the overall nature of the programme and/or cause conflict with stakeholders*
		Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings	*Factor generates uncertainty in the overall nature of the programme and/or could cause conflict with stakeholders/regulators*
TW: Does the amount of uncertainty in capital expenditure affect the decision on the investment programme? UKWIR: Are there concerns that capex uncertainty (particular in relation to new or untested methodologies) could compromise the company's ability to select a best value portfolio over the planning period?			Potential options for SWA zone are groundwater sources and removal of network constraints to allow better transmission of existing water available. There is little uncertainty as to the capital investment required for such schemes but the potential development is relatively small at 9 Mld. Longer term growth will require water to be imported to SWA from the River Thames or via intra zone transfers from SWOX associated with the development of surface water resources in the zone. The nature of the strategic water resource schemes which may serve SWA inevitably means that there will be significant uncertainty associated with cost estimates. For example, potential mitigation required for raw water transfers, to manage water quality and sediment issues, could be

			significant.
TW: Do factors such as lead time and promotability affect the decision on the programme? UKWIR: Does the nature of feasible options mean that construction lead time or scheme promotability are a major driver of the choice of investment portfolio?			Lead time and promotability are not major risk factors affecting transfer and network options in SWA in the short term. Longer term options are potentially more controversial and lead times can be significant. These are factors that are considered as part of the programme appraisal and development and are important considerations alongside other parameters. There is significant difference in the lead time of schemes and experience has demonstrated that lengthy planning inquiries are often associated with the promotion of large new water resource schemes.

TW: Can wider considerations that are non monetisable be properly considered in decision making? UKWIR: Are there concerns that trade-offs between costs and non-monetised "best value" considerations (social, environment) are so complex that they required quantified analysis (beyond SEA) to justify final investment decisions.		There are several factors that need to be considered in developing the best value plan. In addition to financial costs, robust assessment of non-monetised considerations is important. This will involve qualitative and quantitative assessment and it is vital that these assessments are clear and understandable to stakeholders. We are developing a number of metrics to facilitate programme appraisal and development of a best value investment programme. The metrics include cost, adaptability, sustainability, environmental effects, resilience, deliverability and customer preference. Within the SWA zone there is a proposed 10 Mld WRSE export to South East Water which is facilitated by the extensive demand management programme. As such, this is more than a simple supply demand problem.	

TW: Is the investment programme sensitive to assumptions about the utilisation of new resources? UKWIR: Is the investment programme sensitive to assumptions about the utilisation of new resources, mainly because of large differences in variable opex between investment options?		The majority of the short term programme for SWA depends on demand management and groundwater options, neither of which are particularly sensitive to assumptions about utilisation. However, longer term, if a strategic resource option located in SWOX were selected to also supply SWA, utilisation of the new asset would be an important concern.	

Kennet Valley WRZ

1. How big is the problem?

Table 1: Assessment of the strategic needs for WRMP purposes	**No significant concerns (Score = 0)**	**Moderately significant concerns (Score = 1)**	**Very significant concerns (Score = 2)**
Scale of significance		*Is there a sustained deficit caused by a combination of changes in both the supply and demand elements.*	*Could either element cause a sustained deficit by itself, or in combination, presenting a change in the level of service to customers or risk of system failure restrictions i.e. water restrictions such as a rota cut*

TW: Are there current or future risks to available resources which could affect water supply to customers? UKWIR: Level of concern that customer service could be significantly affected by current or future **supply side risks**, without investment.	There was no resource deficit identified in the 25 year baseline DYCP scenario for Kennet Valley in WRMP14. Total WAFU decreases by 4.6 Mld over the 25 year horizon, but 5.5 Mld of available headroom remains in 2040. No new factors have been identified since publication which would increase the level of risk.		
TW: Are there current or future risks to forecast demand which could affect water supply to customers? UKWIR: Level of concern that customer service could be significantly affected by current or future **demand side risks**, without investment		In WRMP14 we forecast an ongoing increase in population of approximately 77 000 people by 2040 in Kennet Valley, equivalent to approximately 14.2 Mld, or 11% of baseline demand. Since publication of WRMP14, revised forecasts have shown a probable further increase in population is likely.	
Scale of significance		*Concerns raised around the level of cost or contentious option in terms of environmental/planning risks.*	*Investment programme that has components that are potentially controversial with costs that large enough to have a material impact on customer bills.*

TW: Is it likely that the investment programme will include some options which are contentious? Will the investment programme likely to have a significant impact on customers' bills? UKWIR: Level of concern over the acceptability of the cost of the likely investment programme, and/or that the likely investment programme contains contentious options (including environmental/planning risks)	Kennet Valley has unused small schemes available totalling up to 59 Mld, which at the current rate of increase in required resource (0.6 Mld per year) could potentially provide enough new resource to supply the baseline supply demand deficit beyond 100 years. There is also extensive demand management planned over the period to 2020 - 2030, which could further reduce the supply demand deficit and ensure contentious, high cost options are not required even for the very long term.		

2. How difficult is the problem to solve?

Assessment of supply side complexity for WRMP purposes

Supply side complexity factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
Scale of significance		*Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings*	*Factor generates uncertainty in the overall nature of the investment programme and/or could cause conflict with stakeholders/regulators*

TW: Are there concerns about the reliability of available resources in the short term and concerns beyond historical record. UKWIR: Are there concerns about **near term** supply system performance either because of recent level of service failures or because of poor understanding of system reliability/resilience under different or more severe droughts than those contained in the historic record? Is this exacerbated by uncertainties about the benefits of optional interventions contained in the Drought Plan?	Kennet Valley WRZ is primarily made up of two large sub-areas (Reading and Newbury) and smaller island zones supplied from groundwater (60%), supported by a surface water abstraction from the lower River Kennet. Connections between the sub-area and island zones are limited, and there are areas of isolated network. The groundwater sources have proven to be stable within drought and so the critical drought element is the surface water source on the River Kennet at Fobney. The WBGW Scheme provides sufficient resilience for Fobney for the most severe drought on record.		
TW: Are there concerns about the performance of the system in the future? UKWIR: Are there concerns about future supply system performance, primarily due to uncertain impacts of climate change on vulnerable supply systems, including associated	Climate change reduction in DO in Kennet Valley WRZ is 5 Mld by 2040, or 3% of WAFU, which uncertainty may increase to 4.5%, a risk of low concern. The 40% surface water resource may be vulnerable to decrease of water quality or pollution incidents, although planned connection of Reading and Newbury supply		

source deterioration (water quality, catchments) or poor understanding	areas should mitigate this risk.		
TW: Are there potential stepped changes in the available resources in the short to midterm? UKWIR: Are there concerns about the potential for "stepped" changes in supply (e.g. sustainability reductions, bulk imports etc.) in the near or medium term that are currently uncertain?	There are no potential sustainability reductions or bulk exports planned for the Kennet Valley zone. Minor interconnectivity exists with both South East Water and Southern Water to the south and east of the Zone, and to Henley and SWOX WRZs, but no water is transferred under normal operation.		

TW: Is the reliability of the available resources affected by other factors? UKWIR: Are there concerns that "DO" metric might fail to reflect resilience aspects that influence the choice of investment options (e.g. duration of failure), or are there conjunctive dependencies between new options (i.e. the amount of benefit from one option depends on the construction of another option). These can both be considered as non-linear problems.	New sources are likely to be groundwater schemes for the near and medium-term future, which are unlikely to be contentious and likely to be highly resilient.		

Assessment of demand side complexity for WRMP purposes

Demand side complexity factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
		Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings	*Factor generates uncertainty in the overall nature of the programme and/or could cause conflict with stakeholders/regulators*
TW: Are there concerns about changes in the demand for water in the short term? UKWIR: Are there concerns about changes in current or near term demand e.g. in terms of demand profile, total demand, or changes in economics/demographics or customer characteristics		In 2014 the GLA published revised population and property projections in the London Plan which are significantly higher than the previous forecast included in our WRMP14, published in August 2014. The population could be as much as 700 000 higher in 2040, and migration to commuter areas such as Reading or Newbury is a likely transferred effect of the increase in the capital. As such it is a medium risk programme, vulnerable to changes in population growth. Our WRMP14 includes substantial savings from demand management dependent on customers changing their water use behaviour and as such is not directly controllable by Thames Water. The Preferred Plan has savings in Kennet Valley over	

		the period to 2030 equating to 5.9 Mld, which only increases security of supply within the zone, and as such this programme is not seen as a significant risk.	
TW: Is the uncertainty over forecasts of population and property sufficient to change the investment? UKWIR: Does uncertainty associated with forecasts of demographic/ economic/ behavioural changes over the planning period cause concerns over the level of investment that may be required.		There is uncertainty in population and property forecasts. GLA produced scenarios which reflects the uncertainty in the forecasts. The range between the most conservative and most optimistic forecasts is 3.9 million people, which is equivalent to around 600 Mld of water required. This has a potential transferred affect to Reading, Newbury and the wider Kennet Valley due to increased migration from London.	
TW: Is demand sensitive to, and varies significantly, during periods of drought? UKWIR: Are there concerns that a simple "dry year/normal year" assessment of demand is not adequate e.g. because of high sensitivity to demand to drought (so demand under severe events needs to be		For planning purposes we assume that customers will reduce their water demand during periods of drought. Potential maximum cumulative savings for L1-L3 restrictions in the Thames Valley based on 2005/6 data is 19.1%. (Thames Water Drought Plan 2013). However we anticipate the potential for savings will change as a result of progressive household metering and non-household	

understood) or because demand versus drought timing is critical		competition. As such, reliance on historical water use patterns in the future is medium risk.	

Assessment of the investment programme complexity for WRMP purposes

Investment Programme Complexity Factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
Scale of significance		*Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings*	*Uncertainty in the overall nature of the programme and/or cause conflict with stakeholders*
		Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings	*Factor generates uncertainty in the overall nature of the programme and/or could cause conflict with stakeholders/regulators*

TW: Does the amount of uncertainty in capital expenditure affect the decision on the investment programme? UKWIR: Are there concerns that capex uncertainty (particular in relation to new or untested methodologies) could compromise the company's ability to select a best value portfolio over the planning period?	Potential options for Kennet Valley zone are groundwater sources and removal of a network constraint to allow better transmission of existing water available. There is little uncertainty as to the capital investment required for such schemes.		
TW: Do factors such as lead time and promotability affect the decision on the programme? UKWIR: Does the nature of feasible options mean that construction lead time or scheme promotability are a major driver of the choice of investment portfolio?	Lead time and promotability are not major risk factors affecting groundwater and network options.		

TW: Can wider considerations that are non monetisable be properly considered in decision making? UKWIR: Are there concerns that trade-offs between costs and non-monetised "best value" considerations (social, environment) are so complex that they required quantified analysis (beyond SEA) to justify final investment decisions.	There are several factors that need to be considered in developing the best value plan. In addition to financial costs, robust assessment of non-monetised considerations is important. This will involve qualitative and quantitative assessment and it is vital that these assessments are clear and understandable to stakeholders. We are developing a number of metrics to facilitate programme appraisal and development of a best value investment programme. The metrics include cost, adaptability, sustainability, environmental effects, resilience, deliverability and customer acceptability.		
TW: Is the investment programme sensitive to assumptions about the utilisation of new resources? UKWIR: Is the investment programme sensitive to assumptions about the utilisation of new resources, mainly because of large	The majority of the programme for Kennet Valley depends on demand management and is not sensitive to assumptions about utilisation.		

differences in variable opex between investment options?			

Guildford WRZ

1. How big is the problem?

Table 1: Assessment of the strategic needs for WRMP purposes	**No significant concerns (Score = 0)**	**Moderately significant concerns (Score = 1)**	**Very significant concerns (Score = 2)**
Scale of significance		*Is there a sustained deficit caused by a combination of changes in both the supply and demand elements.*	*Could either element cause a sustained deficit by itself, or in combination, presenting a change in the level of service to customers or risk of system failure restrictions i.e. water restrictions such as a rota cut*
TW: Are there current or future risks to available resources which could affect water supply to customers? UKWIR: Level of concern that customer service could be significantly affected by current or future **supply side risks**, without investment.	A supply-demand deficit was identified in the 25 year baseline DYCP scenario for Guildford in WRMP14, starting in 2021 and increasing to -3.8 Mld by 2040. However, total WAFU decreases by only 0.46 Mld over the 25 year horizon, less than 1%. Mitigation of the deficit risk is planned through demand management in the near and medium term, although a groundwater scheme (ASR Abbotsfield, Guildford) is also required in 2039 to support the planned 2.7Mld WRSE regional		

	treated water transfer to Affinity Water (Ladymead, Guildford) starting in 2036. This is not seen as a significant concern.		
TW: Are there current or future risks to forecast demand which could affect water supply to customers? UKWIR: Level of concern that customer service could be significantly affected by current or future **demand side risks**, without investment		In WRMP14 we forecast an ongoing increase in population of approximately 12 thousand people by 2040 in Guildford, equivalent to an average household demand of approximately 1.9 Mld, or 3% of total demand. Since publication of WRMP14, revised forecasts have shown that a probable further increase in population is likely.	
Scale of significance		*Concerns raised around the level of cost or contentious option in terms of environmental/planning risks.*	*Investment programme that has components that are potentially controversial with costs that large enough to have a material impact on customer bills.*

TW: Is it likely that the investment programme will include some options which are contentious? Will the investment programme likely to have a significant impact on customers' bills? UKWIR: Level of concern over the acceptability of the cost of the likely investment programme, and/or that the likely investment programme contains contentious options (including environmental/planning risks)		Guildford has only two undeveloped small resource options, which could meet the forecast supply-demand gap over the next 25 years (3.8 Mld). Demand management is planned, to reduce the deficit by 3.2 Mld, ensuring that only the ASR scheme is required before 2040. The reduction in demand is partially driven by the imposition of variable tariffs and customer research has shown that this option is not popular. As such there is a risk of higher demand growth and possible insufficient savings from demand management which means it may be necessary to develop alternative options within the next WRMP planning period. There are transfer connections from Guildford with Affinity Water to the north (export) and South East Water to the South (not in use) which could be renegotiated or alternative sources of supply may need to be found.	

2. How difficult is the problem to solve?

Assessment of supply side complexity for WRMP purposes

Supply side complexity factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
Scale of significance		*Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings*	*Factor generates uncertainty in the overall nature of the investment programme and/or could cause conflict with stakeholders/regulators*
TW: Are there concerns about the reliability of available resources in the short term and concerns beyond historical record. UKWIR: Are there concerns about **near term** supply system performance either because of recent level of service failures or because of poor understanding of system reliability/resilience under different or more severe droughts than those contained in the historic record? Is this exacerbated by uncertainties about the benefits of optional interventions contained in the Drought Plan?	Guildford WRZ is operated as two distinct sub-areas, Shalford and Albury. There is limited movement of water between the two areas, although risk of supply failure is low as isolated areas are both in surplus and contingency plans are in place. Solutions to connect the areas are understood and costed but are not considered a priority given the resilience of the water sources in extreme drought scenarios. The groundwater sources (50% of supply) have proven to be stable within drought and so the critical drought element is the surface water supply at Shalford, which can be abstracted from the River Wey or the River Tillingbourne. The		

	Shalford source has historically been robust through drought periods such that its yield could be maintained during the droughts experienced over the period of record. Our Drought Plan demonstrates that it is robust to more extreme droughts.		
TW: Are there concerns about the performance of the system in the future? UKWIR: Are there concerns about future supply system performance, primarily due to uncertain impacts of climate change on vulnerable supply systems, including associated source deterioration (water quality, catchments) or poor understanding		Climate change reduction is not reported as a significant component of deployable in Guildford WRZ (0.5 Mld). However, in the medium to longer term it is assumed that the recharge and yield rates for the aquifer storage and recovery scheme at Abbotswood will be achieved, providing 4.5 Mld peak supply in summer. Until the scheme has been tested, and due to the lack of alternative resources of sufficient capacity, this remains a risk to avoiding a supply-demand deficit.	
TW: Are there potential stepped changes in the available resources in the short to midterm? UKWIR: Are there concerns about the potential for		There are no potential sustainability reductions planned for the Guilford zone, although a 2.7Mld WRSE treated water regional transfer to Affinity Water (Ladymead, Guildford) will start in 2036. There is potential for additional development of this	

"stepped" changes in supply (e.g. sustainability reductions, bulk imports etc.) in the near or medium term that are currently uncertain?		transfer, and a transfer agreement with South East Water.	
TW: Is the reliability of the available resources affected by other factors? UKWIR: Are there concerns that "DO" metric might fail to reflect resilience aspects that influence the choice of investment options (e.g. duration of failure), or are there conjunctive dependencies between new options (i.e. the amount of benefit from one option depends on the construction of another option). These can both be considered as non-linear problems.	There is limited understanding of how successive dry winters may affect the storage element of the Guildford ASR scheme, but this is not seen as a significant concern at this time. Our draft Drought Plan 2016 has demonstrated the supply system is resilient to extreme droughts.		

Assessment of demand side complexity for WRMP purposes

Demand side complexity factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
		Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings	*Factor generates uncertainty in the overall nature of the programme and/or could cause conflict with stakeholders/regulators*
TW: Are there concerns about changes in the demand for water in the short term? UKWIR: Are there concerns about changes in current or near term demand e.g. in terms of demand profile, total demand, or changes in economics/demographics or customer characteristics		In 2014 the GLA published revised population and property projections in the London Plan which are significantly higher than the previous forecast included in our WRMP14, published in August 2014. The population could be as much as 700,000 higher in 2040, and migration to commuter areas such as Guildford is a likely transferred effect of the increase in the capital. As such it is a medium risk programme, vulnerable to changes in population growth. Our WRMP14 includes substantial savings from demand management dependent on customers changing their water use behaviour and as such is not directly controllable by Thames Water. The Preferred Plan has savings in Guildford over the period to 2040 equating to 3.2 Mld,	

		delivering almost 70% of the total water required in the medium term to maintain security of supply.	
TW: Is the uncertainty over forecasts of population and property sufficient to change the investment? UKWIR: Does uncertainty associated with forecasts of demographic/ economic/ behavioural changes over the planning period cause concerns over the level of investment that may be required.		There is uncertainty in population and property forecasts. GLA produced scenarios which reflects the uncertainty in the forecasts. The range between the most conservative and most optimistic forecasts is 3.9 million people, which is equivalent to around 600 Mld of water required. This has a potential transferred affect to Guildford zone due to increased migration from London.	
TW: Is demand sensitive to, and varies significantly, during periods of drought? UKWIR: Are there concerns that a simple "dry year/normal year" assessment of demand is not adequate e.g. because of high sensitivity to demand to drought (so demand under severe events needs to be understood) or because demand versus drought timing		For planning purposes we assume that customers will reduce their water demand during periods of drought. Potential maximum cumulative savings for L1-L3 restrictions in the Thames Valley based on 2005/6 data is 19.1%. (Thames Water Drought Plan 2013). However we anticipate the potential for savings will change as a result of progressive household metering and non-household competition. As such, reliance on historical water use patterns in the	

is critical		future is medium risk.	

Assessment of the investment programme complexity for WRMP purposes

Investment Programme Complexity Factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
Scale of significance		*Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings*	*Uncertainty in the overall nature of the programme and/or cause conflict with stakeholders*
		Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings	*Factor generates uncertainty in the overall nature of the programme and/or could cause conflict with stakeholders/regulators*

TW: Does the amount of uncertainty in capital expenditure affect the decision on the investment programme? UKWIR: Are there concerns that capex uncertainty (particular in relation to new or untested methodologies) could compromise the company's ability to select a best value portfolio over the planning period?	Potential options for Guildford zone are a groundwater source ASR option, and possibly new transfer agreements. There is little uncertainty as to the capital investment required for such schemes given our previous investment in London in this type of scheme.		
TW: Do factors such as lead time and promotability affect the decision on the programme? UKWIR: Does the nature of feasible options mean that construction lead time or scheme promotability are a major driver of the choice of investment portfolio?	Lead time and promotability are not major risk factors affecting groundwater and ASR, or transfer agreement options in the Guildford zone. The potential investment is not forecast to be required until the end of the planning period giving sufficient time to investigate other options if necessary.		

TW: Can wider considerations that are non monetisable be properly considered in decision making? UKWIR: Are there concerns that trade-offs between costs and non-monetised "best value" considerations (social, environment) are so complex that they required quantified analysis (beyond SEA) to justify final investment decisions.	There are several factors that need to be considered in developing the best value plan. In addition to financial costs, robust assessment of non-monetised considerations is important. This will involve qualitative and quantitative assessment and it is vital that these assessments are clear and understandable to stakeholders. Thames Water is developing a number of metrics to facilitate programme appraisal and development of a best value investment programme. The metrics include cost, adaptability, sustainability, environmental effects, resilience, deliverability and customer acceptability.		
TW: Is the investment programme sensitive to assumptions about the utilisation of new resources? UKWIR: Is the investment programme sensitive to assumptions about the utilisation of new resources, mainly because of large	The majority of the programme for Guildford is likely to depend on demand management or groundwater/ aquifer recharge and is not sensitive to assumptions about utilisation.		

differences in variable opex between investment options?			

Henley WRZ

1. How big is the problem?

Table 1: Assessment of the strategic needs for WRMP purposes	**No significant concerns (Score = 0)**	**Moderately significant concerns (Score = 1)**	**Very significant concerns (Score = 2)**
Scale of significance		*Is there a sustained deficit caused by a combination of changes in both the supply and demand elements.*	*Could either element cause a sustained deficit by itself, or in combination, presenting a change in the level of service to customers or risk of system failure restrictions i.e. water restrictions such as a rota cut*
TW: Are there current or future risks to available resources which could affect water supply to customers? UKWIR: Level of concern that customer service could be significantly affected by current or future **supply side risks**, without investment.	There is no supply-demand deficit identified in the 25 year baseline DYCP scenario for Henley in WRMP14. WAFU does not decrease over the 25 year horizon, supply side risks are not a significant concern.		

TW: Are there current or future risks to forecast demand which could affect water supply to customers? UKWIR: Level of concern that customer service could be significantly affected by current or future **demand side risks**, without investment	In WRMP14 Thames Water forecast an increase in the population of approximately 11 thousand people by 2040 in Henley, equivalent to approximately 1.7 Mld average household consumption, or 9% of total demand. Since publication of WRMP14, revised forecasts have shown a probable further increase in population is likely. However, the zone is in sufficient surplus to enable the forecast increase without additional capacity being required, and a planned demand management programme should ensure that even though the population forecast may increase, demand should not exceed the current WAFU.		
Scale of significance		*Concerns raised around the level of cost or contentious option in terms of environmental/planning risks.*	*Investment programme that has components that are potentially controversial with costs that large enough to have a material impact on customer bills.*

TW: Is it likely that the investment programme will include some options which are contentious? Will the investment programme likely to have a significant impact on customers' bills? UKWIR: Level of concern over the acceptability of the cost of the likely investment programme, and/or that the likely investment programme contains contentious options (including environmental/planning risks)	Henley WRZ is unlikely to require additional resource over the next 25 years, and should circumstances change, there is an undeveloped groundwater scheme which could increase WAFU to 133% of current capacity. Should demand continue to increase at current forecast rates, this would provide sufficient capacity for approximately 100 years.		

2. How difficult is the problem to solve?

Assessment of supply side complexity for WRMP purposes

Supply side complexity factors	**No significant concerns (Score = 0)**	**Moderately significant concerns (Score = 1)**	**Very significant concerns (Score = 2)**
Scale of significance		*Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings*	*Factor generates uncertainty in the overall nature of the investment programme and/or could cause conflict with stakeholders/regulators*
TW: Are there concerns about the reliability of available resources in the short term and concerns beyond historical record. UKWIR: Are there concerns about **near term** supply system performance either because of recent level of service failures or because of poor understanding of system reliability/resilience under different or more severe droughts than those contained in the historic record? Is this exacerbated by uncertainties about the benefits of optional interventions contained in the	The Henley WRZ is supplied entirely from groundwater and has a relatively simple distribution network. There are no remaining unresolved isolated supply areas. These groundwater sources have proved to be robust to drought, for the period of record since the 1976 drought. Although they would be assessed against more severe droughts there is unlikely to be significant concern.		

Drought Plan?			
TW: Are there concerns about the performance of the system in the future? UKWIR: Are there concerns about future supply system performance, primarily due to uncertain impacts of climate change on vulnerable supply systems, including associated source deterioration (water quality, catchments) or poor understanding	Climate change reduction is not reported as a significant component in Henley WRZ (0 Mld).		

TW: Are there potential stepped changes in the available resources in the short to midterm? UKWIR: Are there concerns about the potential for "stepped" changes in supply (e.g. sustainability reductions, bulk imports etc.) in the near or medium term that are currently uncertain?	There are no potential sustainability reductions planned for the Henley WRZ. There is interconnectivity with both Kennet Valley WRZ (to the South) and SWOX WRZ (to the West), but under normal operation there is no movement of water across the WRZ boundary, and these are unlikely to be brought into use.		
TW: Is the reliability of the available resources affected by other factors? UKWIR: Are there concerns that "DO" metric might fail to reflect resilience aspects that influence the choice of investment options (e.g. duration of failure), or are there conjunctive dependencies between new options (i.e. the amount of benefit from one option depends on the construction of another option). These can both be considered as non-	There are few concerns about resilience of the available resources.		

linear problems.			

Assessment of demand side complexity for WRMP purposes

Demand side complexity factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
		Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings	*Factor generates uncertainty in the overall nature of the programme and/or could cause conflict with stakeholders/regulators*

TW: Are there concerns about changes in the demand for water in the short term? UKWIR: Are there concerns about changes in current or near term demand e.g. in terms of demand profile, total demand, or changes in economics/demographics or customer characteristics		In 2014 the GLA published revised population and property projections in the London Plan which are significantly higher than the previous forecast included in Thames Water's WRMP14, published in August 2014. The population could be as much as 700 000 higher in 2040, and migration to commuter areas such as Henley is a likely transferred effect of the increase in the capital. Thames Water's WRMP14 includes substantial savings from demand management dependent on customers changing their water use behaviour and as such is not directly controllable by Thames Water. The Preferred Plan has savings in Henley over the period to 2040 equating to 1.2 Mld in the short/medium term, which helps to maintain the surplus within the zone.	
TW: Is the uncertainty over forecasts of population and property sufficient to change the investment? UKWIR: Does uncertainty associated with forecasts of demographic/ economic/ behavioural changes over the planning period cause		There is uncertainty in population and property forecasts. GLA produced scenarios which reflects the uncertainty in the forecasts. The range between the most conservative and most optimistic forecasts is 3.9 million people, which is equivalent to around 600 Mld of water required. This has a potential transferred affect to Henley zone due to increased	

concerns over the level of investment that may be required.		migration from London.	
TW: Is demand sensitive to, and varies significantly, during periods of drought? UKWIR: Are there concerns that a simple "dry year/normal year" assessment of demand is not adequate e.g. because of high sensitivity to demand to drought (so demand under severe events needs to be understood) or because demand versus drought timing is critical		For planning purposes Thames Water assume that customers will reduce their water demand during periods of drought. Potential maximum cumulative savings for L1-L3 restrictions in the Thames Valley based on 2005/6 data is 19.1%. (Thames Water Drought Plan 2013). However we anticipate the potential for savings will change as a result of progressive household metering and non-household competition. As such, reliance on historical water use patterns in the future is medium risk.	

Assessment of the investment programme complexity for WRMP purposes

Investment Programme Complexity Factors	No significant concerns (Score = 0)	Moderately significant concerns (Score = 1)	Very significant concerns (Score = 2)
Scale of significance		*Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings*	*Uncertainty in the overall nature of the programme and/or cause conflict with stakeholders*
		Potential to change the composition of the investment programme in terms of schemes and/or gross cost rather than just timings	*Factor generates uncertainty in the overall nature of the programme and/or could cause conflict with stakeholders/regulators*
TW: Does the amount of uncertainty in capital expenditure affect the decision on the investment programme? UKWIR: Are there concerns that capex uncertainty (particular in relation to new or untested methodologies) could compromise the company's ability to select a best value portfolio over the planning period?	Potential option for Henley WRZ is a groundwater source. There is confidence in the capital investment required.		

TW: Do factors such as lead time and promotability affect the decision on the programme? UKWIR: Does the nature of feasible options mean that construction lead time or scheme promotability are a major driver of the choice of investment portfolio?	Lead time and promotability are not major risk factors affecting the development of groundwater resources.		
TW: Can wider considerations that are non monetisable be properly considered in decision making? UKWIR: Are there concerns that trade-offs between costs and non-monetised "best value" considerations (social, environment) are so complex that they required quantified analysis (beyond SEA) to justify final investment decisions.	There are several factors that need to be considered in developing the best value plan. In addition to financial costs, robust assessment of non-monetised considerations is important. This will involve qualitative and quantitative assessment and it is vital that these assessments are clear and understandable to stakeholders. Thames Water is developing a number of metrics to facilitate programme appraisal and development of a best value investment programme. The metrics include cost, adaptability, sustainability, environmental effects, resilience, deliverability and customer acceptability.		

TW: Is the investment programme sensitive to assumptions about the utilisation of new resources? UKWIR: Is the investment programme sensitive to assumptions about the utilisation of new resources, mainly because of large differences in variable opex between investment options?	Potential option for Henley WRZ is a groundwater source, so comparative utilisation of different options is not an issue.		

Annex 2: Planning horizon

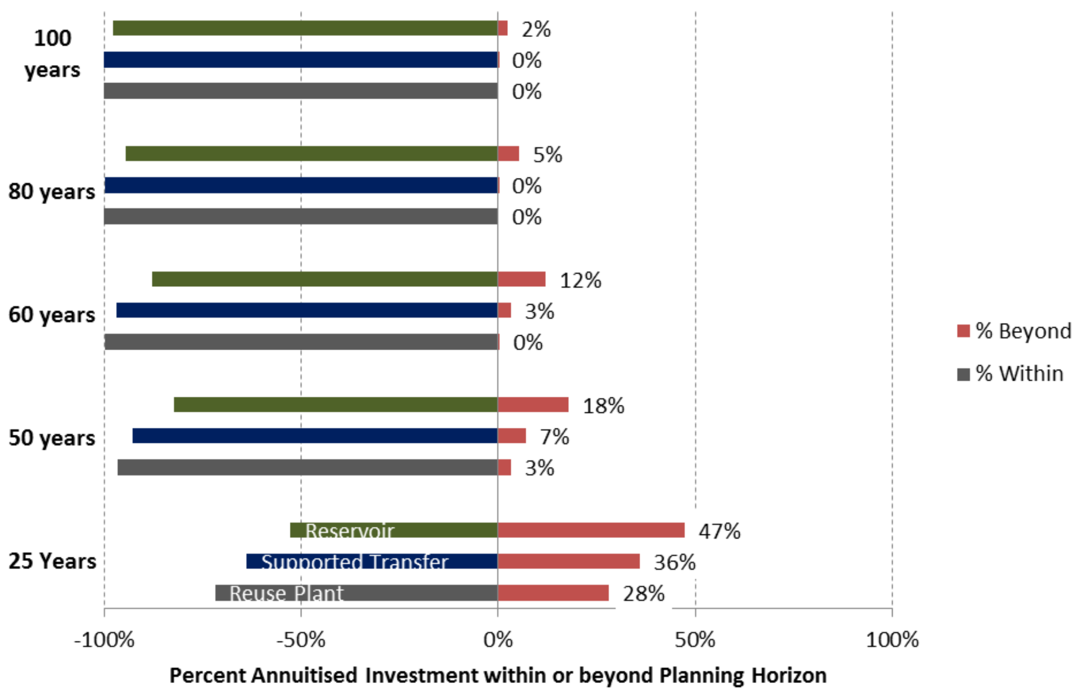
W.277 There are several reasons to consider extending the planning horizon for a zone, and several reasons why it may be unnecessary or infeasible. NERA has condensed them into a series of five questions:

1) Are discounted net costs beyond the proposed horizon substantial?
2) Are asset lives considerably longer than the proposed horizon?
3) Are rapid low-cost solutions insufficient for needs within the proposed horizon?
4) Is there strong concern about events beyond the proposed horizon?
5) Can reasonable forecasts be generated to extend the proposed horizon?

Discounted net costs

W.278 Costs have been annuitized for all types of large water resource option as per the method developed by NERA, for immediate construction start. The percentage annuitized investment beyond a series of planning horizons is shown in Figure W-32.

Figure W-32: Annuitized investment of large water resource options across different planning horizons



W.279 As such it can be seen that while discounted costs of large options beyond a 25 year planning horizon are significant and could affect investment, beyond 60 years they are small, and beyond 80 years insubstantial.

Asset life

W.280 The predominant asset lives of our large options are (Table W-29):

Table W-29: Median asset life of strategic options

Option type	Capex category	Asset life (yrs)
DRA	Treatment works (civils)	60
Desalination plant	Treatment works (civils)	60
Reuse plant	Treatment works (civils)	60
Transfer pipeline	Raw water transport: Tunnels and conduits	80
Reservoir	Raw water abstraction: Storage reservoirs and lakes	250

W.281 Asset lives for all are considerably longer than a 25 year planning horizon. However, beyond 60 years the remaining asset life for the majority of the options is not considerable, and past 80 years only the reservoir options would not incur significant replacement costs to extend asset life.

Sufficient low-cost rapid solutions

W.282 Within the London WRZ, there are not sufficient low-cost options to meet the supply-demand gap over a 25 year planning horizon, as demonstrated by WRMP14. For the remaining WRZs, the available small supply options from WRMP14 have been compared to the 25 year supply demand gap (Table W-30).

Table W-30: Thames Valley WRZ analysis of deficit and small option capacity

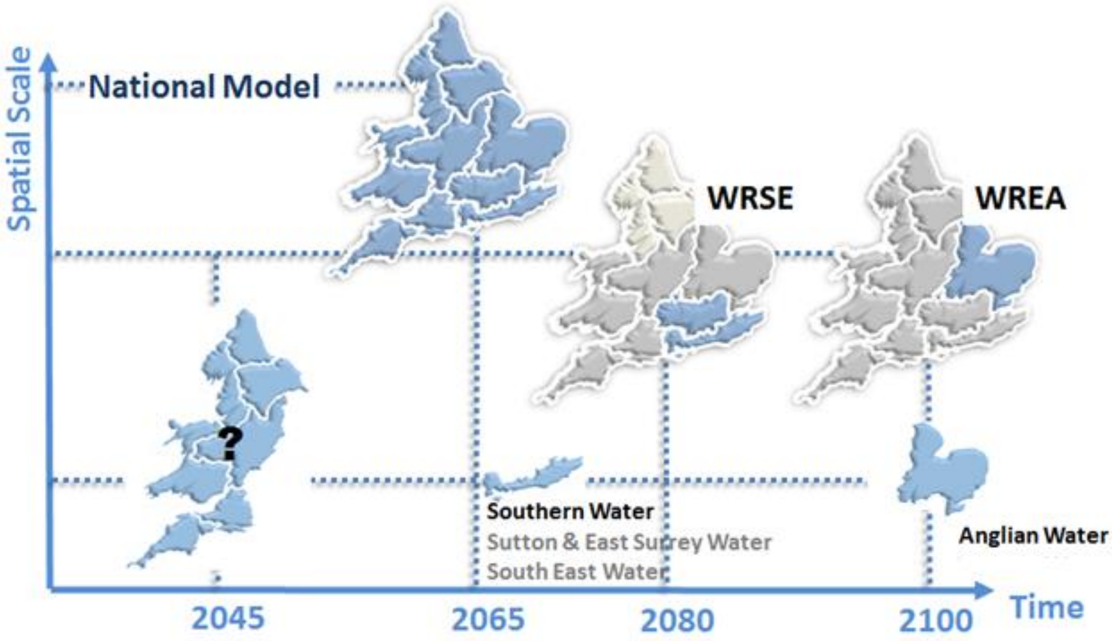
WRZ	DYCP small options (Mld)	Baseline DYCP supply-demand gap increase over 25 years (Mld)	Horizon for which small options sufficient
SWOX	**67.7**	**32.3**	50 years
SWA	**30**	**15.0**	50 years
Kennet	**59.4**	**14.3**	100 years
Guildford	**4.7**	**4.7**	25 years
Henley	**8.5**	**1.3**	100 years

W.283 While this does not take into consideration the significant increases in forecast population since the publication of WRMP14, or the effects of the planned demand management programmes, it does indicate the capability of rapidly available low-cost solutions to supply the Thames Valley WRZs.

Concern for events beyond the current horizon

W.284 Several UK water companies together with a number in the WRSE and WREA regions have stated the intention to plan for a longer period than 25 years, which indicates a high level of concern across the region. The Water UK long-term planning study national model also uses a time horizon to 2065, essentially fifty years from the study date, and the schematic in Figure W-33 shows the distribution of known planning horizons.

Figure W-33: Horizon end points for different water resources plans



W.285 Southern Water is planning for a 50 year horizon and it is likely that several other individual companies which form part of the WRSE group may also do so. WRSE itself plans to assess the problem to 2080, a 60 year horizon, while WREA intends to develop its model to 2100 (80 year horizon), as is Anglian Water.

Generation of reasonable forecasts

W.286 The forecasting of supply or demand into the future depends upon the reliability and extent of the base data forecasts which support them (population, housing, climate change, etc.).

W.287 Population forecasting is being carried out by Professor Phil Rees of Leeds University, who considers that forecasting of water demand should at least be carried out for the life expectancy of someone born today, i.e. upward of 80 years. He also stated that at a national level, the ability to forecast population growth up to 100 years ahead has improved, although noted that at sub-regional levels net migration flows can introduce substantial uncertainty.

W.288 Housing Growth is forecast by the GLA to 2065.

W.289 Climate forecasting was carried out for the 2015 Climate Change Risk Assessment, in which contributing factors for the levels of risk in water resource planning are projected to 2100.

W.290 A feasible cut-off for forecasting supply and demand could be set at 2100 to mirror the availability of baseline population and climate data projections.

Zonal planning horizon extension

W.291 The following pages (Table W-31) show the results of assessing each zone by the above criteria.

Table W-31: Planning Horizon Extension Assessment using NERA method

Question	Scoring of answers			
Are discounted net costs beyond the proposed horizon substantial?	Yes=	0	No=	1
Are asset lives considerably longer than the proposed horizon?	Yes=	0	No=	1
Are rapid low-cost solutions insufficient for needs within the proposed horizon?	Yes=	0	No=	1
Is there strong concern about events beyond the proposed horizon?	Yes=	0	No=	1
Can reasonable forecasts be generated to extend the proposed horizon?	Yes=	0	No=	X

Where the score is 4 it is unnecessary to extend the planning horizon; otherwise the highest score attainable indicates the best horizon or range. The horizon cannot be extended if a reasonable forecast cannot be generated beyond the current period (X).

London	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	Horizon
Substantial Costs?	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	
Asset Life?	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	
Rapid solutions?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Future concerns?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Feasible forecasts?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	
London Score	0	0	0	0	0	0	0	0	2	2	2	2	X				**65 - 80**

SWOX	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	Horizon
Substantial Costs?	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	
Asset Life?	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	
Rapid solutions?	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Future concerns?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Feasible forecasts?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	

SWOX Score	1	1	1	1	1	1	0	0	2	2	2	2	X				**65 - 80**

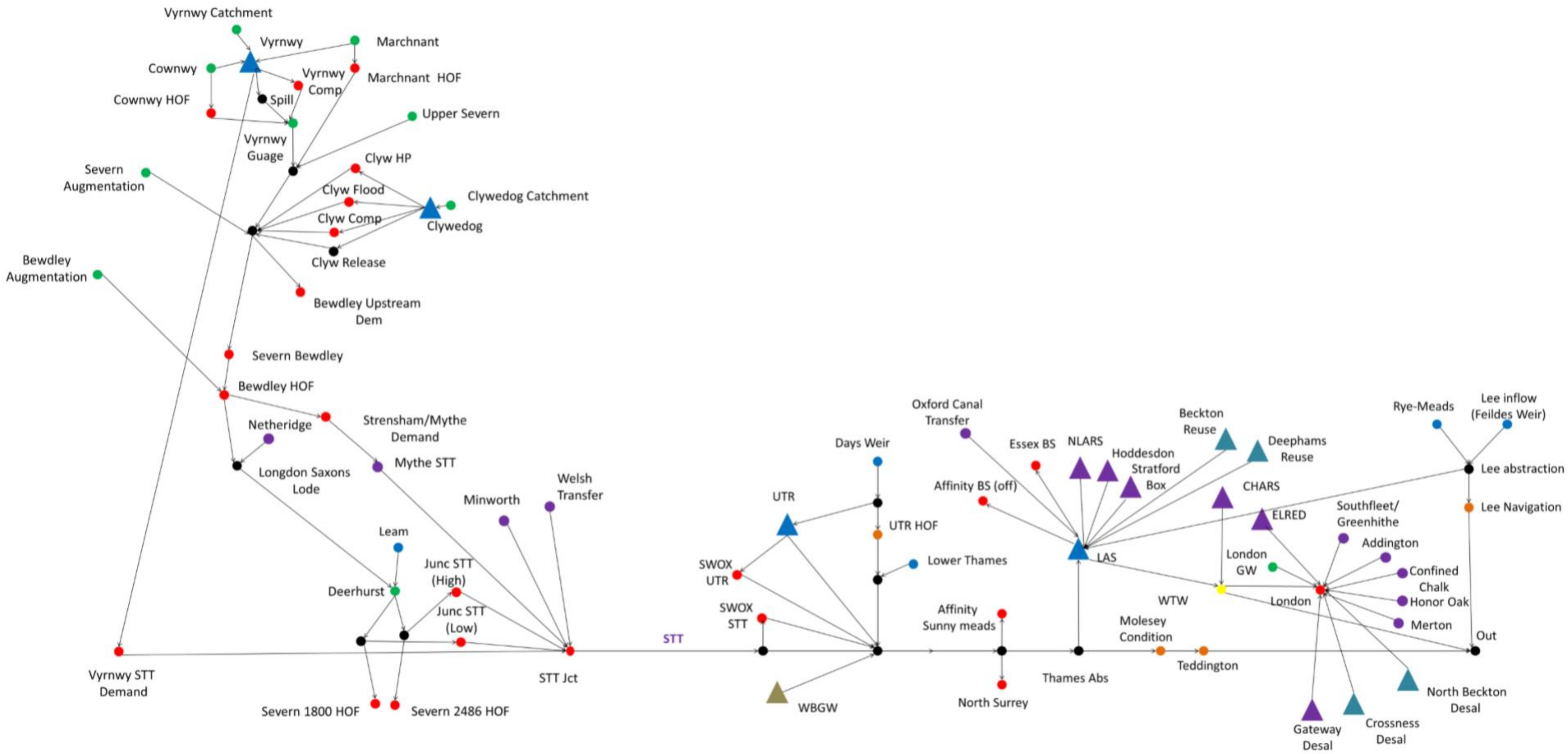
SWA	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**Horizon**
Substantial Costs?	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	
Asset Life?	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	
Rapid solutions?	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Future concerns?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Feasible forecasts?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	
SWA Score	1	1	1	1	1	1	0	0	2	2	2	2	X				**65 - 80**

Kennet Valley	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**Horizon**
Substantial Costs?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Asset Life?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Rapid solutions?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Future concerns?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Feasible forecasts?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	
KV Score	4	4	4	4	4	4	4	4	4	4	4	4	X				**25**

Guildford	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**Horizon**
Substantial Costs?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Asset Life?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Rapid solutions?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Future concerns?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Feasible forecasts?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	
Guildford Score	4	3	3	3	3	3	3	3	3	3	3	3	X				**25**

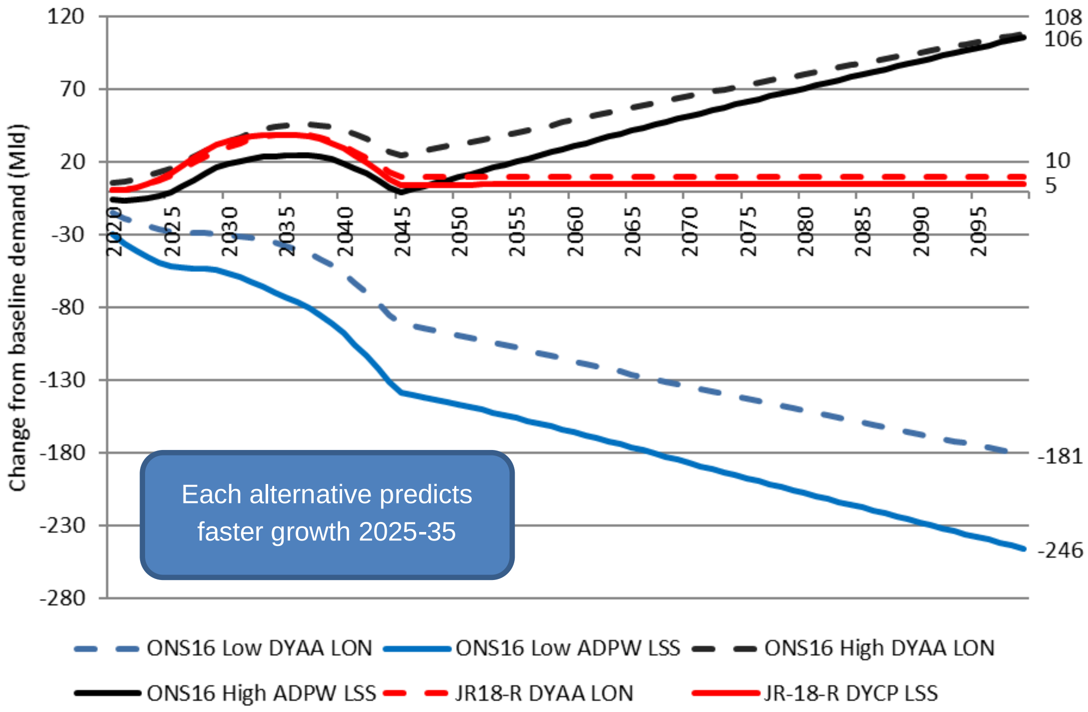
Henley	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	Horizon
Substantial Costs?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Asset Life?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Rapid solutions?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Future concerns?	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Feasible forecasts?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	
Henley Score	4	4	4	4	4	4	4	4	4	4	4	4	X				**25**

Annex 3: Simulation model schematic for Thames and Severn



Annex 4: Drivers for Adaptability scenarios

Figure W-34: Drivers for Adaptability scenarios: Population



W.292 All of the alternative population forecasts predict faster growth than baseline 2025-2035, but slower growth 2035-45.

Figure W-35: Drivers for future change: Per capita consumption

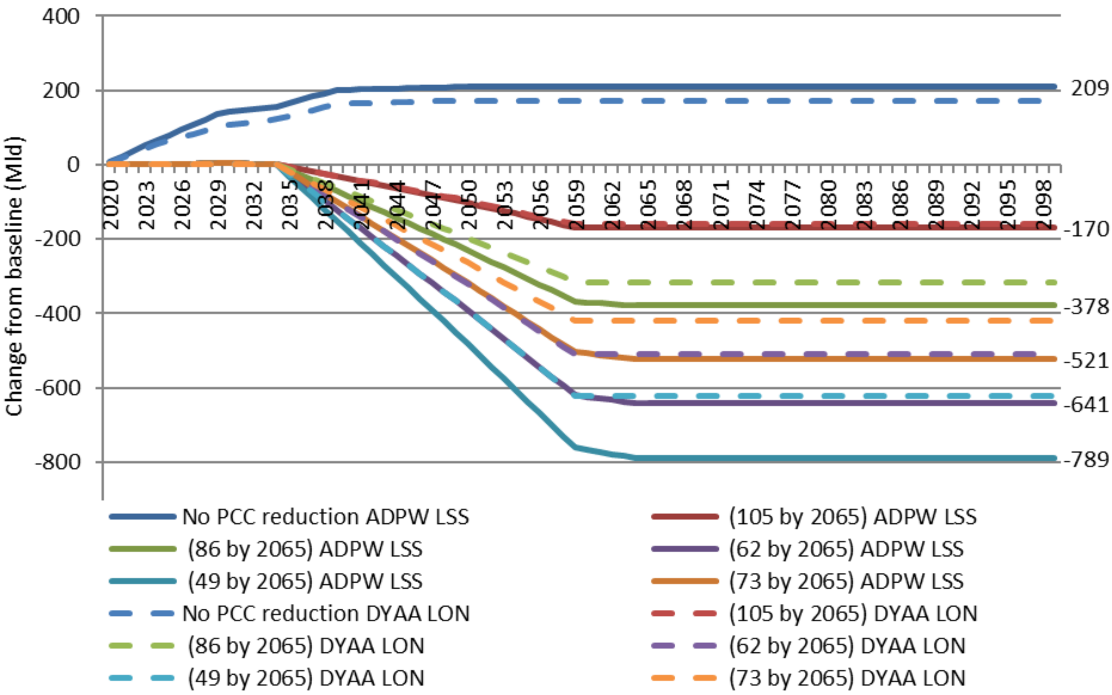


Figure W-36: Drivers for future change: Leakage

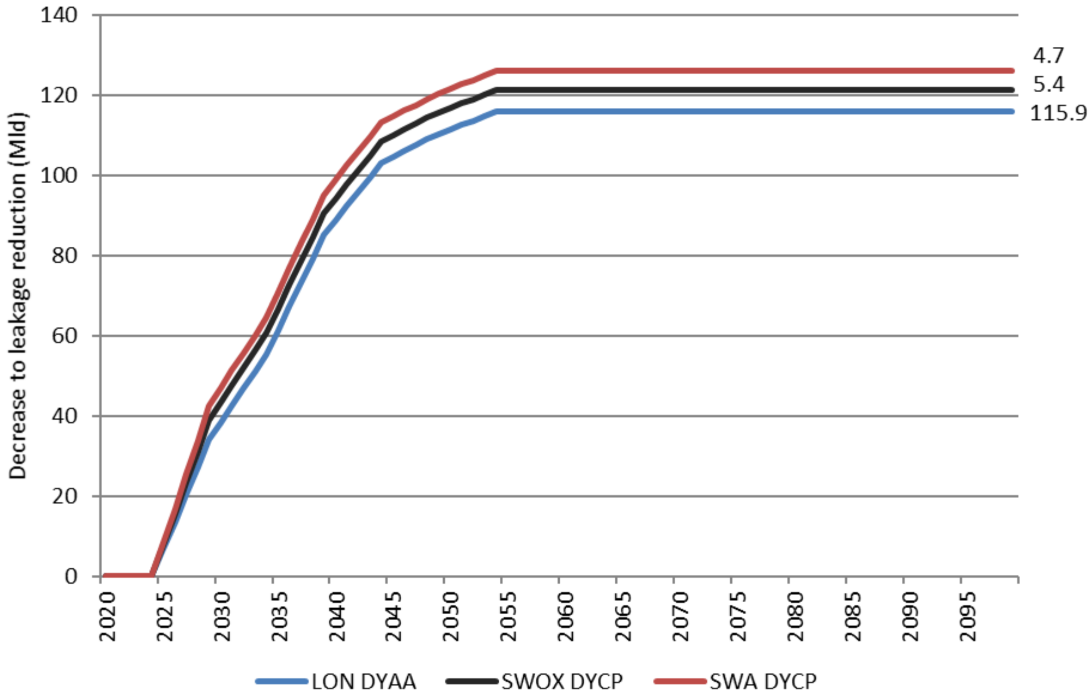


Figure W-37: Drivers for future change: Climate change

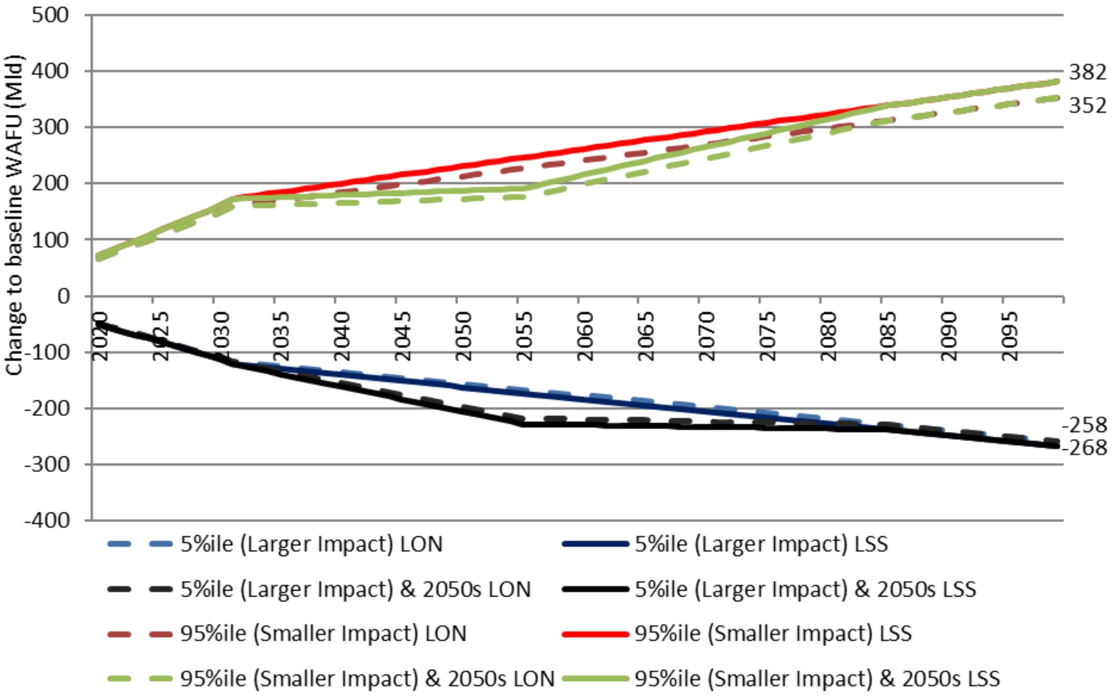


Figure W-38: Drivers for future change: South East Strategic Requirement

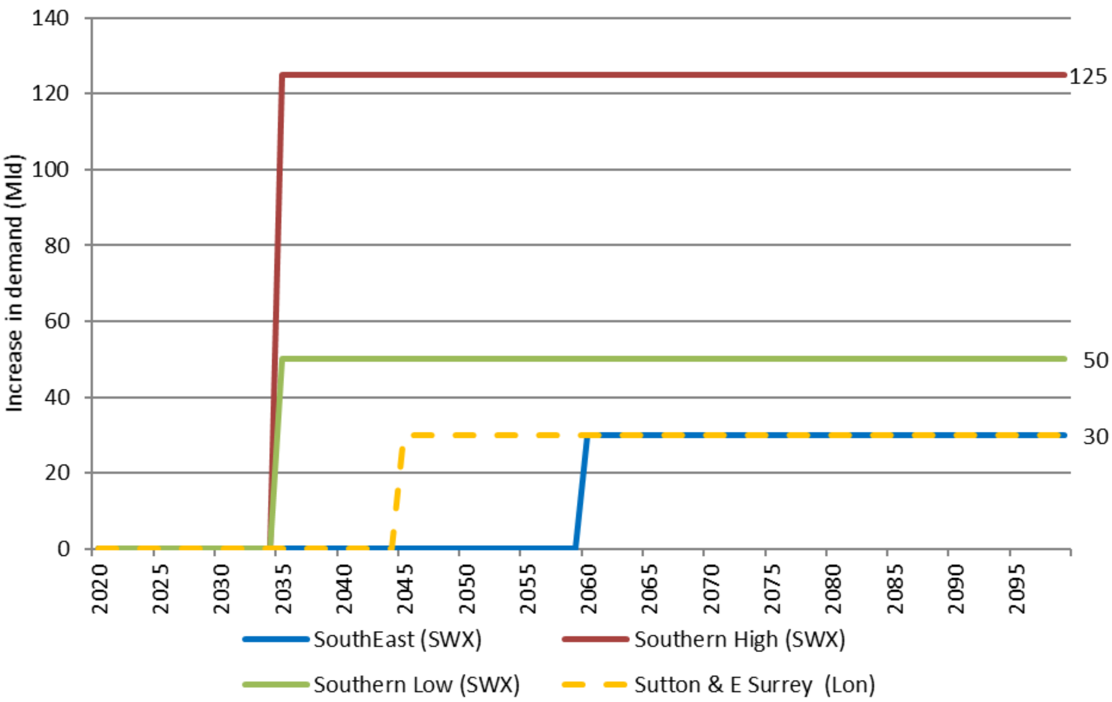


Figure W-39: Range of alternative future scenarios: SWOX DYCP

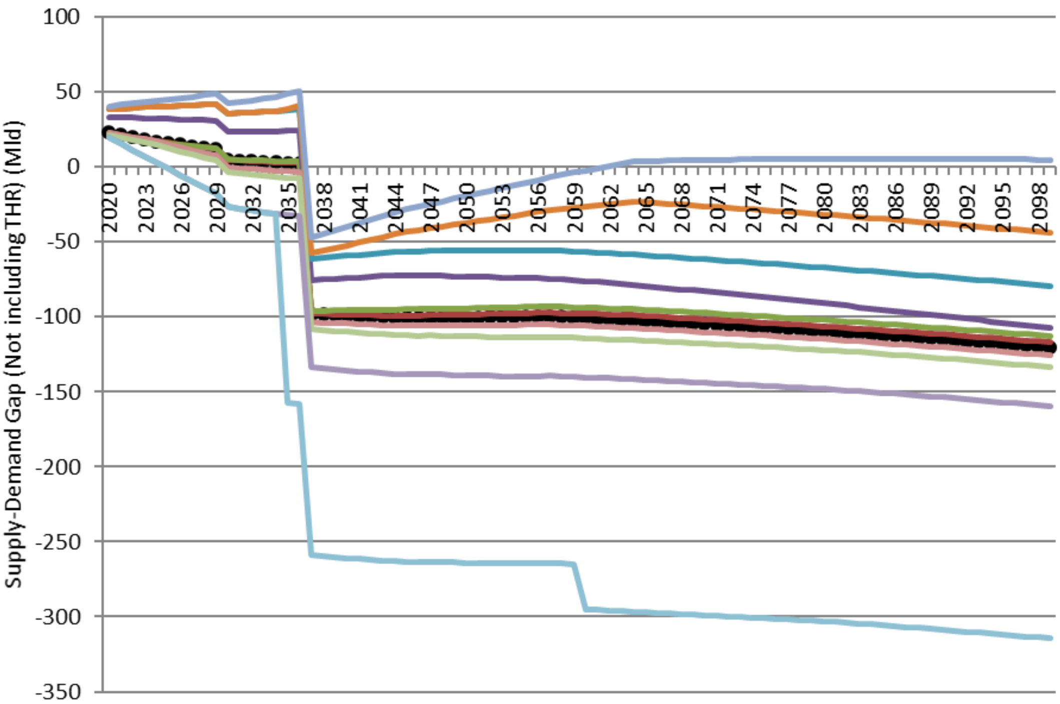
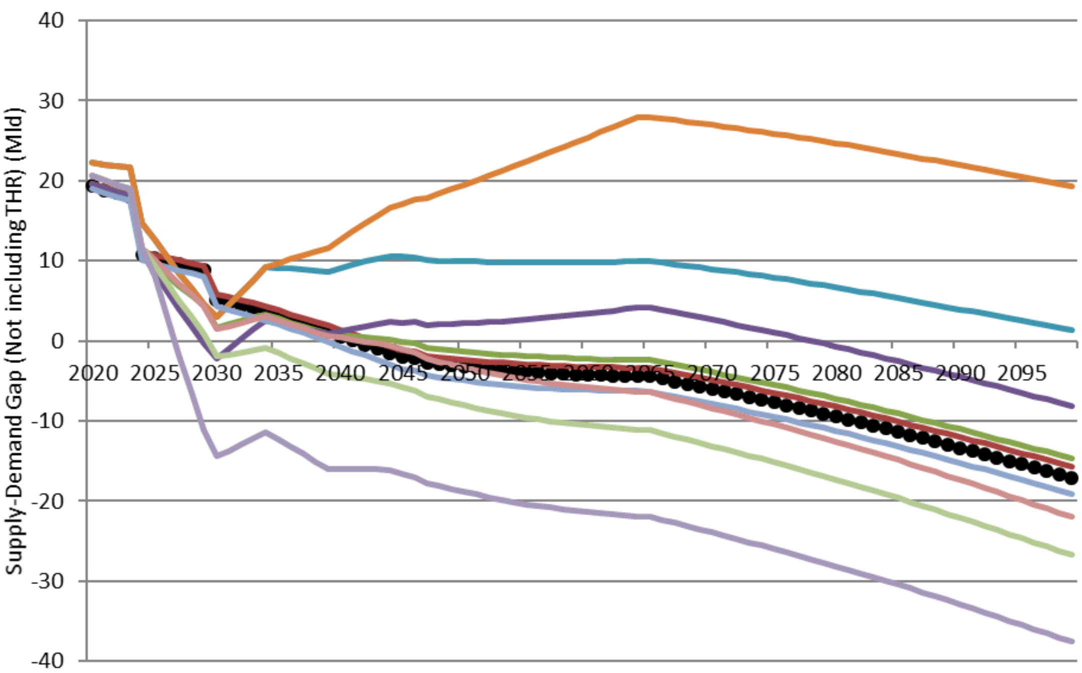


Figure W-40: Range of alternative future scenarios: SWA DYCP



Annex 5: Adaptation pathways

Branch point	2020	2024	2025	2030	2035	2040	2050	2055	2070
Path-N1	P1	P2	P4	P7	P11	P16	P22	P29	P37
Path-N2	P1	P2	P4	P7	P11	P16	P22	P29	P38
Path-N3	P1	P2	P4	P7	P11	P16	P22	P30	P38
Path-N4	P1	P2	P4	P7	P11	P16	P22	P30	P39
Path-N5	P1	P2	P4	P7	P11	P16	P23	P30	P38
Path-N6	P1	P2	P4	P7	P11	P16	P23	P30	P39
Path-N7	P1	P2	P4	P7	P11	P17	P23	P30	P38
Path-N8	P1	P2	P4	P7	P11	P17	P23	P30	P39
Path-N9	P1	P2	P4	P7	P12	P17	P23	P30	P38
Path-N10	P1	P2	P4	P7	P12	P17	P23	P30	P39
Path-N11	P1	P2	P4	P8	P12	P17	P23	P30	P38
Path-N12	P1	P2	P4	P8	P12	P17	P23	P30	P39
Path-N13	P1	P2	P5	P8	P12	P17	P23	P30	P38
Path-N14	P1	P2	P5	P8	P12	P17	P23	P30	P39
Path-N15	P1	P3	P5	P8	P12	P17	P23	P30	P38
Path-N16	P1	P3	P5	P8	P12	P17	P23	P30	P39
Path-N17	P1	P2	P4	P7	P11	P16	P23	P31	P39
Path-N18	P1	P2	P4	P7	P11	P16	P23	P31	P40
Path-N19	P1	P2	P4	P7	P11	P17	P23	P31	P39
Path-N20	P1	P2	P4	P7	P11	P17	P23	P31	P40
Path-N21	P1	P2	P4	P7	P12	P17	P23	P31	P39
Path-N22	P1	P2	P4	P7	P12	P17	P23	P31	P40
Path-N23	P1	P2	P4	P8	P12	P17	P23	P31	P39
Path-N24	P1	P2	P4	P8	P12	P17	P23	P31	P40
Path-N25	P1	P2	P5	P8	P12	P17	P23	P31	P39
Path-N26	P1	P2	P5	P8	P12	P17	P23	P31	P40
Path-N27	P1	P3	P5	P8	P12	P17	P23	P31	P39
Path-N28	P1	P3	P5	P8	P12	P17	P23	P31	P40
Path-N29	P1	P2	P4	P7	P11	P17	P24	P31	P39
Path-N30	P1	P2	P4	P7	P11	P17	P24	P31	P40
Path-N31	P1	P2	P4	P7	P12	P17	P24	P31	P39
Path-N32	P1	P2	P4	P7	P12	P17	P24	P31	P40
Path-N33	P1	P2	P4	P8	P12	P17	P24	P31	P39
Path-N34	P1	P2	P4	P8	P12	P17	P24	P31	P40
Path-N35	P1	P2	P5	P8	P12	P17	P24	P31	P39

Branch point	2020	2024	2025	2030	2035	2040	2050	2055	2070
Path-N36	P1	P2	P5	P8	P12	P17	P24	P31	P40
Path-N37	P1	P3	P5	P8	P12	P17	P24	P31	P39
Path-N38	P1	P3	P5	P8	P12	P17	P24	P31	P40
Path-N39	P1	P2	P4	P7	P12	P18	P24	P31	P39
Path-N40	P1	P2	P4	P7	P12	P18	P24	P31	P40
Path-N41	P1	P2	P4	P8	P12	P18	P24	P31	P39
Path-N42	P1	P2	P4	P8	P12	P18	P24	P31	P40
Path-N43	P1	P2	P5	P8	P12	P18	P24	P31	P39
Path-N44	P1	P2	P5	P8	P12	P18	P24	P31	P40
Path-N45	P1	P3	P5	P8	P12	P18	P24	P31	P39
Path-N46	P1	P3	P5	P8	P12	P18	P24	P31	P40
Path-N47	P1	P2	P4	P8	P13	P18	P24	P31	P39
Path-N48	P1	P2	P4	P8	P13	P18	P24	P31	P40
Path-N49	P1	P2	P5	P8	P13	P18	P24	P31	P39
Path-N50	P1	P2	P5	P8	P13	P18	P24	P31	P40
Path-N51	P1	P3	P5	P8	P13	P18	P24	P31	P39
Path-N52	P1	P3	P5	P8	P13	P18	P24	P31	P40
Path-N53	P1	P2	P5	P9	P13	P18	P24	P31	P39
Path-N54	P1	P2	P5	P9	P13	P18	P24	P31	P40
Path-N55	P1	P3	P5	P9	P13	P18	P24	P31	P39
Path-N56	P1	P3	P5	P9	P13	P18	P24	P31	P40
Path-N57	P1	P3	P6	P9	P13	P18	P24	P31	P39
Path-N58	P1	P3	P6	P9	P13	P18	P24	P31	P40
Path-N59	P1	P2	P4	P7	P11	P17	P24	P32	P40
Path-N60	P1	P2	P4	P7	P11	P17	P24	P32	P41
Path-N61	P1	P2	P4	P7	P12	P17	P24	P32	P40
Path-N62	P1	P2	P4	P7	P12	P17	P24	P32	P41
Path-N63	P1	P2	P4	P8	P12	P17	P24	P32	P40
Path-N64	P1	P2	P4	P8	P12	P17	P24	P32	P41
Path-N65	P1	P2	P5	P8	P12	P17	P24	P32	P40
Path-N66	P1	P2	P5	P8	P12	P17	P24	P32	P41
Path-N67	P1	P3	P5	P8	P12	P17	P24	P32	P40
Path-N68	P1	P3	P5	P8	P12	P17	P24	P32	P41
Path-N69	P1	P2	P4	P7	P12	P18	P24	P32	P40
Path-N70	P1	P2	P4	P7	P12	P18	P24	P32	P41
Path-N71	P1	P2	P4	P8	P12	P18	P24	P32	P40
Path-N72	P1	P2	P4	P8	P12	P18	P24	P32	P41

Branch point	2020	2024	2025	2030	2035	2040	2050	2055	2070
Path-N73	P1	P2	P5	P8	P12	P18	P24	P32	P40
Path-N74	P1	P2	P5	P8	P12	P18	P24	P32	P41
Path-N75	P1	P3	P5	P8	P12	P18	P24	P32	P40
Path-N76	P1	P3	P5	P8	P12	P18	P24	P32	P41
Path-N77	P1	P2	P4	P8	P13	P18	P24	P32	P40
Path-N78	P1	P2	P4	P8	P13	P18	P24	P32	P41
Path-N79	P1	P2	P5	P8	P13	P18	P24	P32	P40
Path-N80	P1	P2	P5	P8	P13	P18	P24	P32	P41
Path-N81	P1	P3	P5	P8	P13	P18	P24	P32	P40
Path-N82	P1	P3	P5	P8	P13	P18	P24	P32	P41
Path-N83	P1	P2	P5	P9	P13	P18	P24	P32	P40
Path-N84	P1	P2	P5	P9	P13	P18	P24	P32	P41
Path-N85	P1	P3	P5	P9	P13	P18	P24	P32	P40
Path-N86	P1	P3	P5	P9	P13	P18	P24	P32	P41
Path-N87	P1	P3	P6	P9	P13	P18	P24	P32	P40
Path-N88	P1	P3	P6	P9	P13	P18	P24	P32	P41
Path-N89	P1	P2	P4	P7	P12	P18	P25	P32	P40
Path-N90	P1	P2	P4	P7	P12	P18	P25	P32	P41
Path-N91	P1	P2	P4	P8	P12	P18	P25	P32	P40
Path-N92	P1	P2	P4	P8	P12	P18	P25	P32	P41
Path-N93	P1	P2	P5	P8	P12	P18	P25	P32	P40
Path-N94	P1	P2	P5	P8	P12	P18	P25	P32	P41
Path-N95	P1	P3	P5	P8	P12	P18	P25	P32	P40
Path-N96	P1	P3	P5	P8	P12	P18	P25	P32	P41
Path-N97	P1	P2	P4	P8	P13	P18	P25	P32	P40
Path-N98	P1	P2	P4	P8	P13	P18	P25	P32	P41
Path-N99	P1	P2	P5	P8	P13	P18	P25	P32	P40
Path-N100	P1	P2	P5	P8	P13	P18	P25	P32	P41
Path-N101	P1	P3	P5	P8	P13	P18	P25	P32	P40
Path-N102	P1	P3	P5	P8	P13	P18	P25	P32	P41
Path-N103	P1	P2	P5	P9	P13	P18	P25	P32	P40
Path-N104	P1	P2	P5	P9	P13	P18	P25	P32	P41
Path-N105	P1	P3	P5	P9	P13	P18	P25	P32	P40
Path-N106	P1	P3	P5	P9	P13	P18	P25	P32	P41
Path-N107	P1	P3	P6	P9	P13	P18	P25	P32	P40
Path-N108	P1	P3	P6	P9	P13	P18	P25	P32	P41
Path-N109	P1	P2	P4	P8	P13	P19	P25	P32	P40

Branch point	2020	2024	2025	2030	2035	2040	2050	2055	2070
Path-N110	P1	P2	P4	P8	P13	P19	P25	P32	P41
Path-N111	P1	P2	P5	P8	P13	P19	P25	P32	P40
Path-N112	P1	P2	P5	P8	P13	P19	P25	P32	P41
Path-N113	P1	P3	P5	P8	P13	P19	P25	P32	P40
Path-N114	P1	P3	P5	P8	P13	P19	P25	P32	P41
Path-N115	P1	P2	P5	P9	P13	P19	P25	P32	P40
Path-N116	P1	P2	P5	P9	P13	P19	P25	P32	P41
Path-N117	P1	P3	P5	P9	P13	P19	P25	P32	P40
Path-N118	P1	P3	P5	P9	P13	P19	P25	P32	P41
Path-N119	P1	P3	P6	P9	P13	P19	P25	P32	P40
Path-N120	P1	P3	P6	P9	P13	P19	P25	P32	P41
Path-N121	P1	P2	P5	P9	P14	P19	P25	P32	P40
Path-N122	P1	P2	P5	P9	P14	P19	P25	P32	P41
Path-N123	P1	P3	P5	P9	P14	P19	P25	P32	P40
Path-N124	P1	P3	P5	P9	P14	P19	P25	P32	P41
Path-N125	P1	P3	P6	P9	P14	P19	P25	P32	P40
Path-N126	P1	P3	P6	P9	P14	P19	P25	P32	P41
Path-N127	P1	P3	P6	P10	P14	P19	P25	P32	P40
Path-N128	P1	P3	P6	P10	P14	P19	P25	P32	P41
Path-N129	P1	P2	P4	P7	P12	P18	P25	P33	P41
Path-N130	P1	P2	P4	P7	P12	P18	P25	P33	P42
Path-N131	P1	P2	P4	P8	P12	P18	P25	P33	P41
Path-N132	P1	P2	P4	P8	P12	P18	P25	P33	P42
Path-N133	P1	P2	P5	P8	P12	P18	P25	P33	P41
Path-N134	P1	P2	P5	P8	P12	P18	P25	P33	P42
Path-N135	P1	P3	P5	P8	P12	P18	P25	P33	P41
Path-N136	P1	P3	P5	P8	P12	P18	P25	P33	P42
Path-N137	P1	P2	P4	P8	P13	P18	P25	P33	P41
Path-N138	P1	P2	P4	P8	P13	P18	P25	P33	P42
Path-N139	P1	P2	P5	P8	P13	P18	P25	P33	P41
Path-N140	P1	P2	P5	P8	P13	P18	P25	P33	P42
Path-N141	P1	P3	P5	P8	P13	P18	P25	P33	P41
Path-N142	P1	P3	P5	P8	P13	P18	P25	P33	P42
Path-N143	P1	P2	P5	P9	P13	P18	P25	P33	P41
Path-N144	P1	P2	P5	P9	P13	P18	P25	P33	P42
Path-N145	P1	P3	P5	P9	P13	P18	P25	P33	P41
Path-N146	P1	P3	P5	P9	P13	P18	P25	P33	P42

Branch point	2020	2024	2025	2030	2035	2040	2050	2055	2070
Path-N147	P1	P3	P6	P9	P13	P18	P25	P33	P41
Path-N148	P1	P3	P6	P9	P13	P18	P25	P33	P42
Path-N149	P1	P2	P4	P8	P13	P19	P25	P33	P41
Path-N150	P1	P2	P4	P8	P13	P19	P25	P33	P42
Path-N151	P1	P2	P5	P8	P13	P19	P25	P33	P41
Path-N152	P1	P2	P5	P8	P13	P19	P25	P33	P42
Path-N153	P1	P3	P5	P8	P13	P19	P25	P33	P41
Path-N154	P1	P3	P5	P8	P13	P19	P25	P33	P42
Path-N155	P1	P2	P5	P9	P13	P19	P25	P33	P41
Path-N156	P1	P2	P5	P9	P13	P19	P25	P33	P42
Path-N157	P1	P3	P5	P9	P13	P19	P25	P33	P41
Path-N158	P1	P3	P5	P9	P13	P19	P25	P33	P42
Path-N159	P1	P3	P6	P9	P13	P19	P25	P33	P41
Path-N160	P1	P3	P6	P9	P13	P19	P25	P33	P42
Path-N161	P1	P2	P5	P9	P14	P19	P25	P33	P41
Path-N162	P1	P2	P5	P9	P14	P19	P25	P33	P42
Path-N163	P1	P3	P5	P9	P14	P19	P25	P33	P41
Path-N164	P1	P3	P5	P9	P14	P19	P25	P33	P42
Path-N165	P1	P3	P6	P9	P14	P19	P25	P33	P41
Path-N166	P1	P3	P6	P9	P14	P19	P25	P33	P42
Path-N167	P1	P3	P6	P10	P14	P19	P25	P33	P41
Path-N168	P1	P3	P6	P10	P14	P19	P25	P33	P42
Path-N169	P1	P2	P4	P8	P13	P19	P26	P33	P41
Path-N170	P1	P2	P4	P8	P13	P19	P26	P33	P42
Path-N171	P1	P2	P5	P8	P13	P19	P26	P33	P41
Path-N172	P1	P2	P5	P8	P13	P19	P26	P33	P42
Path-N173	P1	P3	P5	P8	P13	P19	P26	P33	P41
Path-N174	P1	P3	P5	P8	P13	P19	P26	P33	P42
Path-N175	P1	P2	P5	P9	P13	P19	P26	P33	P41
Path-N176	P1	P2	P5	P9	P13	P19	P26	P33	P42
Path-N177	P1	P3	P5	P9	P13	P19	P26	P33	P41
Path-N178	P1	P3	P5	P9	P13	P19	P26	P33	P42
Path-N179	P1	P3	P6	P9	P13	P19	P26	P33	P41
Path-N180	P1	P3	P6	P9	P13	P19	P26	P33	P42
Path-N181	P1	P2	P5	P9	P14	P19	P26	P33	P41
Path-N182	P1	P2	P5	P9	P14	P19	P26	P33	P42
Path-N183	P1	P3	P5	P9	P14	P19	P26	P33	P41

Branch point	2020	2024	2025	2030	2035	2040	2050	2055	2070
Path-N184	P1	P3	P5	P9	P14	P19	P26	P33	P42
Path-N185	P1	P3	P6	P9	P14	P19	P26	P33	P41
Path-N186	P1	P3	P6	P9	P14	P19	P26	P33	P42
Path-N187	P1	P3	P6	P10	P14	P19	P26	P33	P41
Path-N188	P1	P3	P6	P10	P14	P19	P26	P33	P42
Path-N189	P1	P2	P5	P9	P14	P20	P26	P33	P41
Path-N190	P1	P2	P5	P9	P14	P20	P26	P33	P42
Path-N191	P1	P3	P5	P9	P14	P20	P26	P33	P41
Path-N192	P1	P3	P5	P9	P14	P20	P26	P33	P42
Path-N193	P1	P3	P6	P9	P14	P20	P26	P33	P41
Path-N194	P1	P3	P6	P9	P14	P20	P26	P33	P42
Path-N195	P1	P3	P6	P10	P14	P20	P26	P33	P41
Path-N196	P1	P3	P6	P10	P14	P20	P26	P33	P42
Path-N197	P1	P3	P6	P10	P15	P20	P26	P33	P41
Path-N198	P1	P3	P6	P10	P15	P20	P26	P33	P42
Path-N199	P1	P2	P4	P8	P13	P19	P26	P34	P42
Path-N200	P1	P2	P4	P8	P13	P19	P26	P34	P43
Path-N201	P1	P2	P5	P8	P13	P19	P26	P34	P42
Path-N202	P1	P2	P5	P8	P13	P19	P26	P34	P43
Path-N203	P1	P3	P5	P8	P13	P19	P26	P34	P42
Path-N204	P1	P3	P5	P8	P13	P19	P26	P34	P43
Path-N205	P1	P2	P5	P9	P13	P19	P26	P34	P42
Path-N206	P1	P2	P5	P9	P13	P19	P26	P34	P43
Path-N207	P1	P3	P5	P9	P13	P19	P26	P34	P42
Path-N208	P1	P3	P5	P9	P13	P19	P26	P34	P43
Path-N209	P1	P3	P6	P9	P13	P19	P26	P34	P42
Path-N210	P1	P3	P6	P9	P13	P19	P26	P34	P43
Path-N211	P1	P2	P5	P9	P14	P19	P26	P34	P42
Path-N212	P1	P2	P5	P9	P14	P19	P26	P34	P43
Path-N213	P1	P3	P5	P9	P14	P19	P26	P34	P42
Path-N214	P1	P3	P5	P9	P14	P19	P26	P34	P43
Path-N215	P1	P3	P6	P9	P14	P19	P26	P34	P42
Path-N216	P1	P3	P6	P9	P14	P19	P26	P34	P43
Path-N217	P1	P3	P6	P10	P14	P19	P26	P34	P42
Path-N218	P1	P3	P6	P10	P14	P19	P26	P34	P43
Path-N219	P1	P2	P5	P9	P14	P20	P26	P34	P42
Path-N220	P1	P2	P5	P9	P14	P20	P26	P34	P43

Branch point	2020	2024	2025	2030	2035	2040	2050	2055	2070
Path-N221	P1	P3	P5	P9	P14	P20	P26	P34	P42
Path-N222	P1	P3	P5	P9	P14	P20	P26	P34	P43
Path-N223	P1	P3	P6	P9	P14	P20	P26	P34	P42
Path-N224	P1	P3	P6	P9	P14	P20	P26	P34	P43
Path-N225	P1	P3	P6	P10	P14	P20	P26	P34	P42
Path-N226	P1	P3	P6	P10	P14	P20	P26	P34	P43
Path-N227	P1	P3	P6	P10	P15	P20	P26	P34	P42
Path-N228	P1	P3	P6	P10	P15	P20	P26	P34	P43
Path-N229	P1	P2	P5	P9	P14	P20	P27	P34	P42
Path-N230	P1	P2	P5	P9	P14	P20	P27	P34	P43
Path-N231	P1	P3	P5	P9	P14	P20	P27	P34	P42
Path-N232	P1	P3	P5	P9	P14	P20	P27	P34	P43
Path-N233	P1	P3	P6	P9	P14	P20	P27	P34	P42
Path-N234	P1	P3	P6	P9	P14	P20	P27	P34	P43
Path-N235	P1	P3	P6	P10	P14	P20	P27	P34	P42
Path-N236	P1	P3	P6	P10	P14	P20	P27	P34	P43
Path-N237	P1	P3	P6	P10	P15	P20	P27	P34	P42
Path-N238	P1	P3	P6	P10	P15	P20	P27	P34	P43
Path-N239	P1	P3	P6	P10	P15	P21	P27	P34	P42
Path-N240	P1	P3	P6	P10	P15	P21	P27	P34	P43
Path-N241	P1	P2	P5	P9	P14	P20	P27	P35	P43
Path-N242	P1	P2	P5	P9	P14	P20	P27	P35	P44
Path-N243	P1	P3	P5	P9	P14	P20	P27	P35	P43
Path-N244	P1	P3	P5	P9	P14	P20	P27	P35	P44
Path-N245	P1	P3	P6	P9	P14	P20	P27	P35	P43
Path-N246	P1	P3	P6	P9	P14	P20	P27	P35	P44
Path-N247	P1	P3	P6	P10	P14	P20	P27	P35	P43
Path-N248	P1	P3	P6	P10	P14	P20	P27	P35	P44
Path-N249	P1	P3	P6	P10	P15	P20	P27	P35	P43
Path-N250	P1	P3	P6	P10	P15	P20	P27	P35	P44
Path-N251	P1	P3	P6	P10	P15	P21	P27	P35	P43
Path-N252	P1	P3	P6	P10	P15	P21	P27	P35	P44
Path-N253	P1	P3	P6	P10	P15	P21	P28	P35	P43
Path-N254	P1	P3	P6	P10	P15	P21	P28	P35	P44
Path-N255	P1	P3	P6	P10	P15	P21	P28	P36	P44
Path-N256	P1	P3	P6	P10	P15	P21	P28	P36	P45