Water Resources West Regional Plan decision support tool

Specification note

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Glossary

Metric

These are used to represent each objective and outcome to assess value and to judge and decide on the best value plan. They are referred to as value criteria (or criteria) in the UKWIR (2020) best value plan framework.

Multi Criteria Decision Analysis (MCDA)

MCDA describes any formalised method that enables the solution of a decision problem taking into account multiple criteria. Typically these decision problems are too complex for the informal use of common sense.

Ml/d

Megalitres per day. A common unit of measurement in water resources. One megalitre is equivalent to 1,000,000 litres.

Objectives

These are the specific goals of the WRP. These could be, for example, increasing flows in chalk streams, meeting targets for greenhouse gas emissions, PCC and leakage, improving drinking water quality, achieving a desired environmental destination.

Outcomes

These are the consequences of achieving the objectives of a WRP. These could be, for example, maintaining or improving factors such as the environment, sustainability, resilience, natural capital or service to customers.

Per Capita Consumption (PCC)

Measure of average water use for each person in a water company's appointed area. Companies are required to report estimates for both metered and unmetered customers.

Performance measures

Also referred to as attributes and measures. These provide a means of measuring the metrics (or value criteria) within the MCDA process.

Shortage

A shortage typically describes a situation where the demand for water cannot be met (or cannot be guaranteed to continue to be met in the near future) and drought response measures need to be introduced to manage the consequences appropriately.

Surplus

When water supply exceeds demand.

Supply-demand balance

The difference between water available for use supply and demand at any given point in time and including the uncertainty buffer (target headroom) that water companies apply to their assessments.

Target headroom

Target headroom represents the minimum buffer that companies should plan to maintain between supply and demand for water in order to cater for current and future uncertainties.

Uncertainty

A characteristic of a system or decision where the probability that certain states or outcomes have occurred or may occur can be reasonably anticipated but is not precisely known. 'Deep uncertainty' describes the situation where the probability that certain states or outcomes may occur at all is not precisely known.

Water Resource Zone (WRZ)

The largest possible zone in which all water resources, excluding external transfers, can be shared. Hence, it is the zone in which all customers experience the same risk of supply failure from a resource shortfall.

Summary

Water Resources West (WRW) is developing its regional water resources plan 2024 in parallel with an aligned set of Water Resource Management Plans (WRMPs) for Severn Trent Water, South Staffs Water, United Utilities Water and Dŵr Cymru Welsh Water (DCWW). WRW has commissioned a team led by HR Wallingford to develop a multi-criteria decision tool and guidance that can be used by these water companies and WRW to develop the plans. This report provides the specification for the tool.

It is a regulatory requirement that water companies and regional organisations develop “best value” plans for managing water resources. The UKWIR (2020) framework for best value water resources management plans sets out a multi-criteria decision analysis (MCDA) approach for developing a best value plan. It is proposed in this specification note that the multi-criteria decision tool follows the MCDA approach set out in the UKWIR (2020) BVP framework.

It is proposed that the WRW decision tool be developed in Excel and VBA to meet the preferences of the water companies. The benefits of having a tool in Excel include the familiarity of users with using Excel and the ability for users to see the equations that are behind the calculations.

The WRW decision tool will implement selected tasks within the five steps of the generic approach of the UKWIR (2020) best value plan (BVP) framework. This report sets out how the tool will align with these five steps. Within each of the BVP framework steps there are tasks. The focus of the decision tool will be on:

- Tasks 3.8 and 3.10 on plan generation and assessing performance.
- Tasks 4.1 and 4.2 on determining scores and weights for the metrics.
- Task 5.1 on assessing the performance of alternatives.
- Task 5.2 on sensitivity analysis and stress testing.

The tool will output data and visualisations to enable companies and their stakeholders to evaluate and compare alternative plans.

This report includes an Appendix setting out our proposal for the tasks involved in the next phases of the project and the revised programme and budget (see Appendix C).

Contents

Tables

1. Introduction

1.1. Context

Water Resources West (WRW) is developing its regional water resources plan 2024 in parallel with an aligned set of Water Resource Management Plans (WRMPs) for Severn Trent Water (STWL), South Staffs Water (SSW), United Utilities Water (UU) and Dŵr Cymru Welsh Water (DCWW). WRW has commissioned a team led by HR Wallingford to develop a multi-criteria decision tool and guidance that can be used by these water companies and WRW to develop the plans. This report provides the specification for the tool.

It is a regulatory requirement that water companies and regional organisations develop “best value” plans for managing water resources. The best value concept is that the plan considers not only the least cost options and combinations of options (albeit with minimum requirements for environmental and social outcomes), but that it also considers the outcome against other criteria such as environmental benefit, social and wellbeing measures and resilience, for example. The UKWIR (2020) framework for best value water resources management plans sets out a multi-criteria decision analysis (MCDA) approach for developing a best value plan. It is proposed in this specification note that the multi-criteria decision tool follows the MCDA approach set out in the UKWIR (2020) BVP framework.

1.2. Project overview

WRW has commissioned a team led by HR Wallingford to develop a multi-criteria decision tool and guidance that can be used by these water companies and WRW to develop the plans. This project is being carried out through a phased approach, whereby the scope and budget of each phase is determined following the outcome of the previous phase and discussion of next steps between the project consultant team and WRW. The phases envisaged at this stage of discussions are:

- Phase 1: Scoping. This incorporates the tasks of reviewing previous work, specifying methods and preparing the specification note for the tool. This report is the specification note and presents the findings from Phase 1.
- Phase 2: Tool development and piloting. This involves development of the decision tool in Excel and piloting it on a Water Resource Zone (WRZ) to demonstrate how it can be used.
- Phase 3: Support. This involves the provision of guidance and support to water companies in delivering their plans to contribute to the Regional Plan.

The aim of this specification note is to provide the specification for the tool so that this can be discussed, modified and agreed with WRW and the water companies.

1.3. Report structure

This report is structured as follows:

- Section 2 explains the methodology used in the development of the tool specification.

- Section 3 provides an overview of the specification for the WRW tool.
- Section 4 explains how the tool aligns with the generic approach of the UKWIR (2020) best value plan framework, specifically describing the process of developing inputs for the tool.
- Section 5 explains how the tool aligns with the generic approach of the UKWIR (2020) best value plan framework, specifically describing the functionality and outputs of the tool.
- Section 6 describes the further work that is recommended in order to support the development of inputs for the decision tool and to use the outputs for selecting a preferred plan.
- Section 5 provides conclusions from the report and sets out the next steps for the project.
- The appendices provide further detail on specific parts of the report. Note that Appendix C sets out our updated proposal for Phases 2 and 3 of the project.

2. Methodology

WRW's over-riding objective for the study is to develop a multi-criteria decision tool and guidance that can be used by water companies for WRMP24 for the purposes of achieving a Best Value Plan (BVP).

In order to ensure alignment with WRW methodologies, the project team has reviewed the relevant WRW method statements, outputs from the FastTrack[2] project, and consulted with WRW. Furthermore, the project team has consulted with Wood and Ricardo, who are completing the parallel environmental assessments for WRW. This work has also informed our recommendations in this note, which have been developed to ensure alignment in all relevant areas.

The tool needs to be used by individual water companies rather than by WRW, and it is not necessarily the case that each company needs to have an identical tool. In order to arrive at a specification that is responsive to member company needs, the project team has undertaken a consultation with representatives of each company. This consultation has also informed our recommendations in this note.

3. WRW multi-criteria decision tool specification

3.1. Overview

Our core recommendation driving the specification of the multi-criteria decision tool is that it should be consistent, as far as possible, with the UKWIR (2020) best value plan (BVP) framework. This itself encourages consistency with regulatory guidance.

Within the UKWIR (2020) BVP framework there are five major steps, as illustrated in Figure 3.1. Note that each of the steps comprises several tasks, which are set out in the detailed flow diagrams in Sections 4 and 5.

We recommend that multi-criteria decision tool be designed to take the outcome from Steps 1-3 as inputs. This means that companies will need to have completed Steps 1-3 of the UKWIR (2020) BVP framework in order to be able to use the tool. The form of these inputs, and an outline of the work that will be required to obtain them, are discussed in Section 4. The guidance, which will accompany the tool, will include further details concerning how these steps should be undertaken based on the guidance in the UKWIR (2020) BVP framework as applied to WRW circumstances.

The multi-criteria decision tool itself will be designed to facilitate specific tasks within Steps 3, 4 and 5. This means that it will be possible for companies to use the tool to generate and compare plans. Sections 3.3 and 5 provide further details of the form of the tool, how it will work, and the form of the outputs that will be produced.

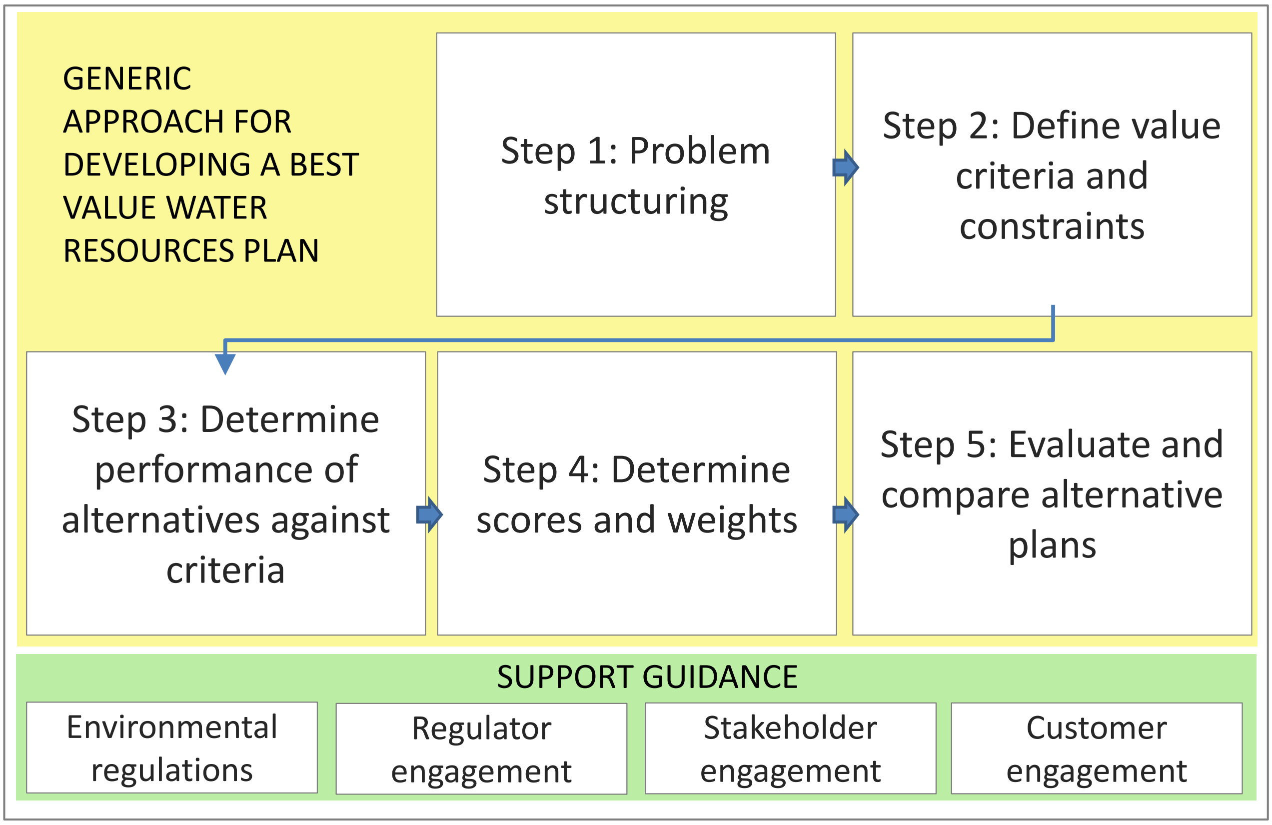

Figure 3.1: Overview of the UKWIR (2020) framework for developing a best value water resources plan

Source: UKWIR (2020)

3.2. Requirements for the tool

The decision tool must support the water companies to meet the requirements of regulatory guidance on water resource management planning. It is a regulatory requirement that the water companies and the region present the following plans for consultation:

- The least cost plan as determined through the Economics of Balancing Supply and Demand (EBSD) approach.
- The best value plan that includes metrics assessed through Strategic Environmental Assessment (SEA).
- The best value plan that includes metrics assessed through Natural Capital Assessment (NCA).
- The best value plan that includes metrics assessed through Biodiversity Net Gain (BNG) assessment.

To achieve the final three requirements listed above, the tool will enable data from these different assessments to be included for the metrics for which they provide results. There are many other requirements in the regulatory guidance and supplementary notes that the water companies will need to take into account throughout the development of their water resources management plans.

To understand the specific requirements of the WRW water companies for the decision tool, interviews were carried out (in the case of SSW the interview questions were answered offline in the interview questionnaire template). The findings from these interviews are set out in Appendix A. The interviews highlighted some key requirements for the tool as follows:

1. The tool must enable the inclusion of company-specific metrics in addition to the eight[1] metrics identified through the collaborative WRW decision process.
2. The tool must enable water companies to adjust scores and weights to obtain trade-offs between various programmes[2].
3. The tool must support the plan generation process.
4. The tool must not be developed in a way that sensitive information of each company (such as cost of schemes) is visible to other companies in WRW as this would breach competition laws.
5. The preferred environment for developing the tool is Microsoft Excel.

3.3. Tool specification

The overriding requirement of WRW is to have a tool that can be delivered quickly and enable the water companies to use a simple and pragmatic approach for developing their draft plans to feed into the draft Regional Plan by August 2020. The tool needs to enable the generation of plans (with scheduling) as well as the selection of a best value plan.

Figure 3.2 shows the proposed components of the decision tool (i.e. the inputs and outputs) and the pre- and post- process steps required for using the tool. The overall approach will be a weighted sum optimisation method for plan generation and selection. We explain these components and steps in Appendix C.

[1] The list of eight metrics is set out in Section 4.2 and becomes twelve metrics when considering both positive and negative effects for selected metrics.

[2] Note the words programme and plan are used interchangeably in this report, to mean the set of options that are selected for the candidate plans/programmes that are then assessed through the multi-criteria decision tool to support the wider programme appraisal process that selects the preferred plan/programme for inclusion in the WRMP.

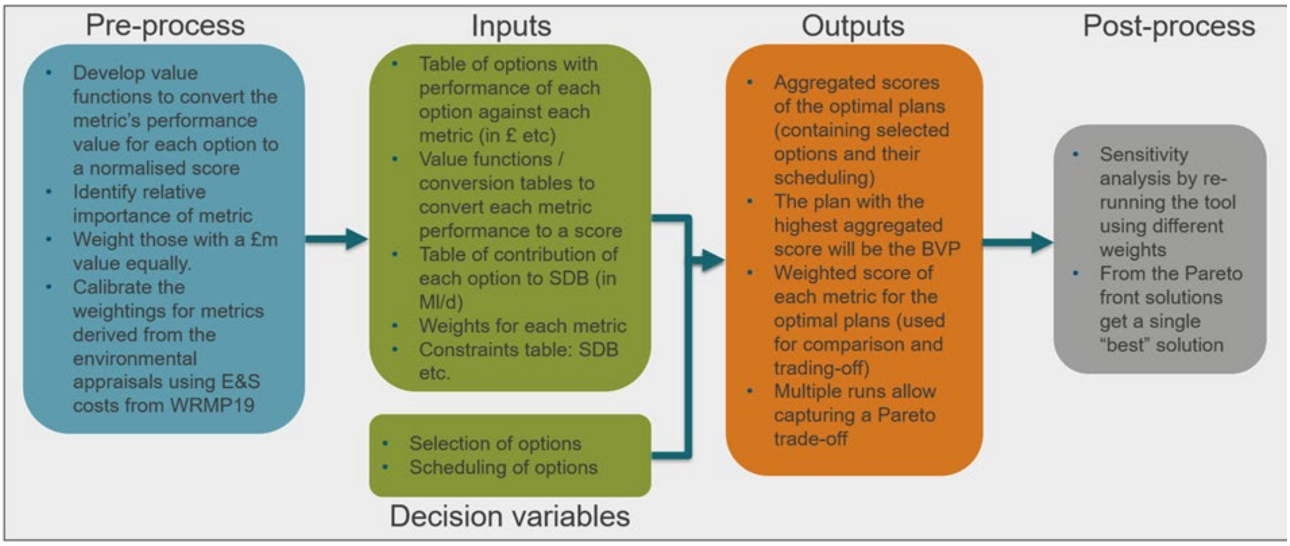

Figure 3.2: Components of the decision tool (inputs and outputs) and pre- and post- process steps

3.4. Approaches for eliciting metric weights

The information in this section is provided for context. Through discussion with WRW it has been agreed that metric weights will be elicited through a workshop.

There are different methods available for eliciting weights for metrics, each with pros and cons, and some of which are more easily implemented in Excel than others. We recommend use of the swing-weighting method and bisection method to elicit scores and weights as these can be most easily implemented in Excel. We are, however, flexible on the approach and can discuss what will best suit the needs of the WRW water companies.

Figure 3.3 provides a non-exhaustive overview of weighting methods employed in MCDA.

- In the direct weighting method, participants provide their assessment of the importance of criteria by allocating a weight between a set of points, e.g. allocating 100 points across the criteria in a manner that reflect their importance.
- In pairwise comparison, participants compare pairs of criteria and options, indicating their relative importance on a scale.
- In MAUT methods preferences are elicited in a manner that corresponds with the axioms of utility theory — transitivity, completeness, independence.

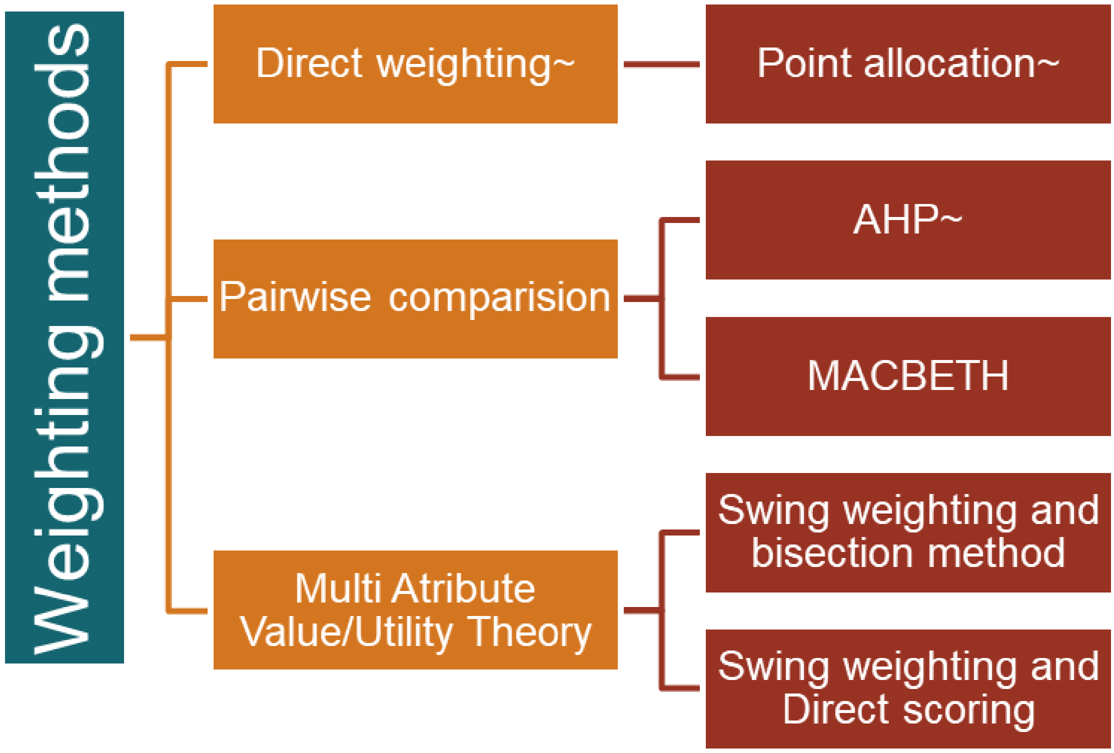

Figure 3.3: Overview of weighting methods employed in MCDA

Notes: ~ Not recommended as not grounded in standard economic theory of choice

To choose the elicitation method, the following elements will need to be considered:

- **Internal validity of the elicitation method.**

Certain methods might look attractive as they are easy to implement and provide answers to. However, "easy" preference elicitation methods such as AHP and simple direct weighting/rating exercises are not grounded in standard economic theory of choice and therefore do not capture actual value judgements and preferences for trading off one criterion against another. As such, the project team does not recommend direct weighting methods and AHP.

To make such assessments, it is crucial to balance the cognitive burden of the task and not oversimplify the problem which could compromise the internal validity of the model. The MAUT based approaches and MACBETH style of pairwise comparisons are recommended.

- **Personal preference from the client as to the ease of answering the types of questions in the different methods.**

Pairwise comparison can be an attractive form of eliciting subjective judgement as users find it more straightforward and convenient. While the AHP method has been subject to substantial debate and critique among MCDA specialist (see for supplementary MCDA guidance of the Green Book for a review of the criticism on its theoretical foundations and properties), there are alternative approaches to AHP, such as MACBETH. In this method, the procedure asks participants to assess the attractiveness difference between each pair of options as one of six levels. After having completed the pairwise comparisons, a series of four computer programmes processes these data to calculate a set of scores for the plans (on a scale from 0 to

100). One of the main strengths of this approach is that it enables the evaluation of inconsistencies within the judgements, and guides the participant through steps to amend the inputs until consistent scores are obtained. Figure 3.4 provides some illustrative examples of the pairwise comparison inputs that will be required.

Figure 3.4: MACBETH illustration of pairwise comparison

Another theoretically sound method for eliciting weights and scores is the **Swing Weighting (trade offs between metrics) and Bisection Method (strength of preference within metrics).** This method follows a different procedure for eliciting strengths of preference between the metrics. As opposed to pairwise comparisons elicitation method, this one can be found less intuitive and more challenging to answer, thus requiring more consistency checks. A simpler and quicker version of the Bisection Method is the Swing Weighting and Direct Scoring method. The drawback of this method is that it does not enable the flexibility of adding new plans once the workshop has been completed, as opposed to the bisection method which will enable incorporating new plans (provided that it falls within the range of performance elicited). Figure 3.5 provides some illustrative examples of the pairwise comparison inputs that will be required.

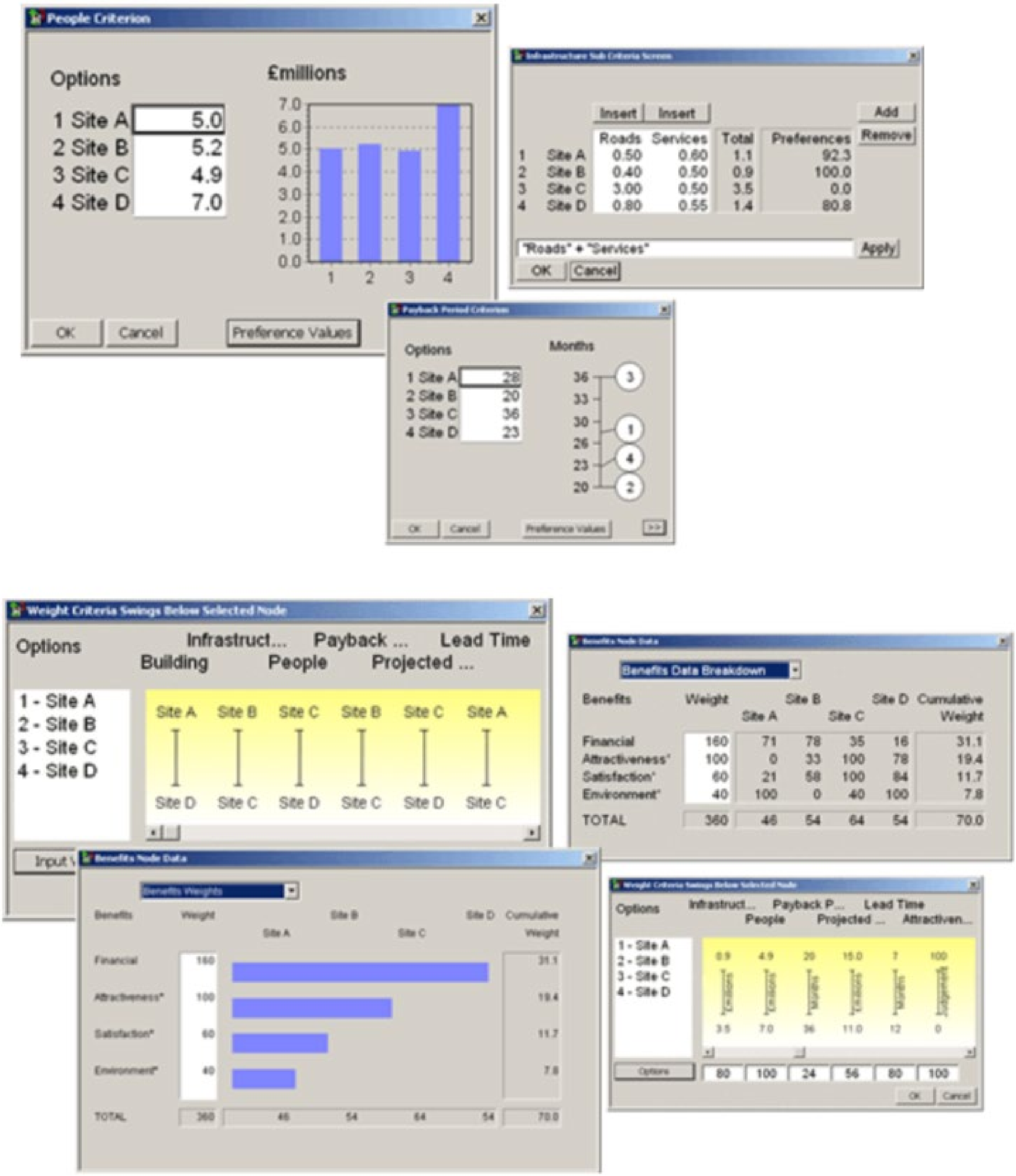

Figure 3.5: Swing Weighting and Bisection methods illustration for HIVIEW3

- **Practicality of implementation** (i.e. ability to implement in Excel, web tools, or even suitability of existing tools).

It should be noted that the different methods to elicit the preferences will require a different mathematical model to be implemented in the background, some more time consuming than others to implement, and some more and less suited to different platforms.

For reference, Table 3.1 provides a summary of the existing software on the market for the methods described above.

Table 3.1: Summary of tools available and key features

Tool	Elicitation type	Direct rating	Bisection method and swing weighting	Pairwise comparison	Grounded in standard economic theory of choice	Web based	Display multiple stakeholder views
Hiview3	MAVT/MAUT & MACBETH	Yes	Yes	Yes (MACBETH)	Yes	No	No
V.I.S.A	MAVT/MAUT	Yes	Yes	No	Yes	Yes	Yes
Entscheidungsnavi	MAVT/MAUT	Yes	Yes	No	Yes	Yes	No
MACBETH	Pairwise comparison	Yes	Yes	Yes	Yes	No	?
Transparant choice	AHP	No	No	Yes	No	Yes	Yes
MakeItRational	AHP	No	No	Yes	No	Yes	Yes

Abbreviations: AHP: Analytic Hierarchy Process, MACBETH: Measuring Attractiveness by a Categorical Based Evaluation Technique; MAVT: Multi attribute value theory; MAUT: Multi attribute utility theory.

It is worth bearing in mind that providing such value judgement information is always a challenging task, and regardless of the method chosen by the companies, facilitation will be required to support this elicitation.

4. Developing the tool inputs (UKWIR BVP Steps 1 – 3)

4.1. Step 1: Problem structuring

Step 1 in the generic approach of the UKWIR (2020) best value plan framework is devoted to problem structuring and involves the tasks as shown in Figure 4.1. This step should be completed by the water companies in advance of using the decision tool and will not be supported by the tool functionality.

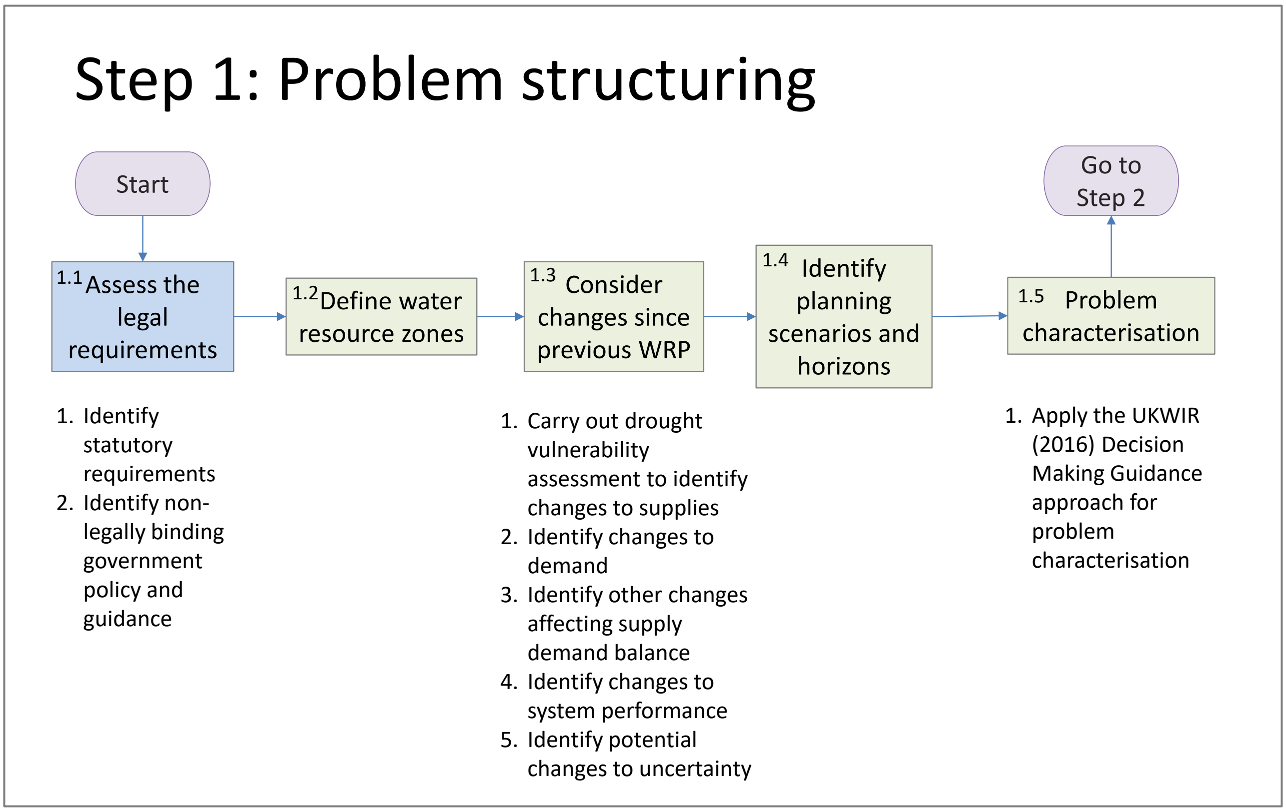

Figure 4.1: Step 1: Problem structuring

Source: UKWIR (2020)

4.2. Step 2: Define value criteria (metrics) and constraints

Step 2 in the generic approach of the UKWIR (2020) best value plan framework is to define value criteria and constraints. WRW refers to value criteria as metrics and we therefore refer to these as metrics throughout this report. The tasks for carrying this out are shown in Figure 4.2. The metrics, their performance measures and constraints are the means by which the desired objectives and outcomes of the plan can be taken into account in the MCDA process.

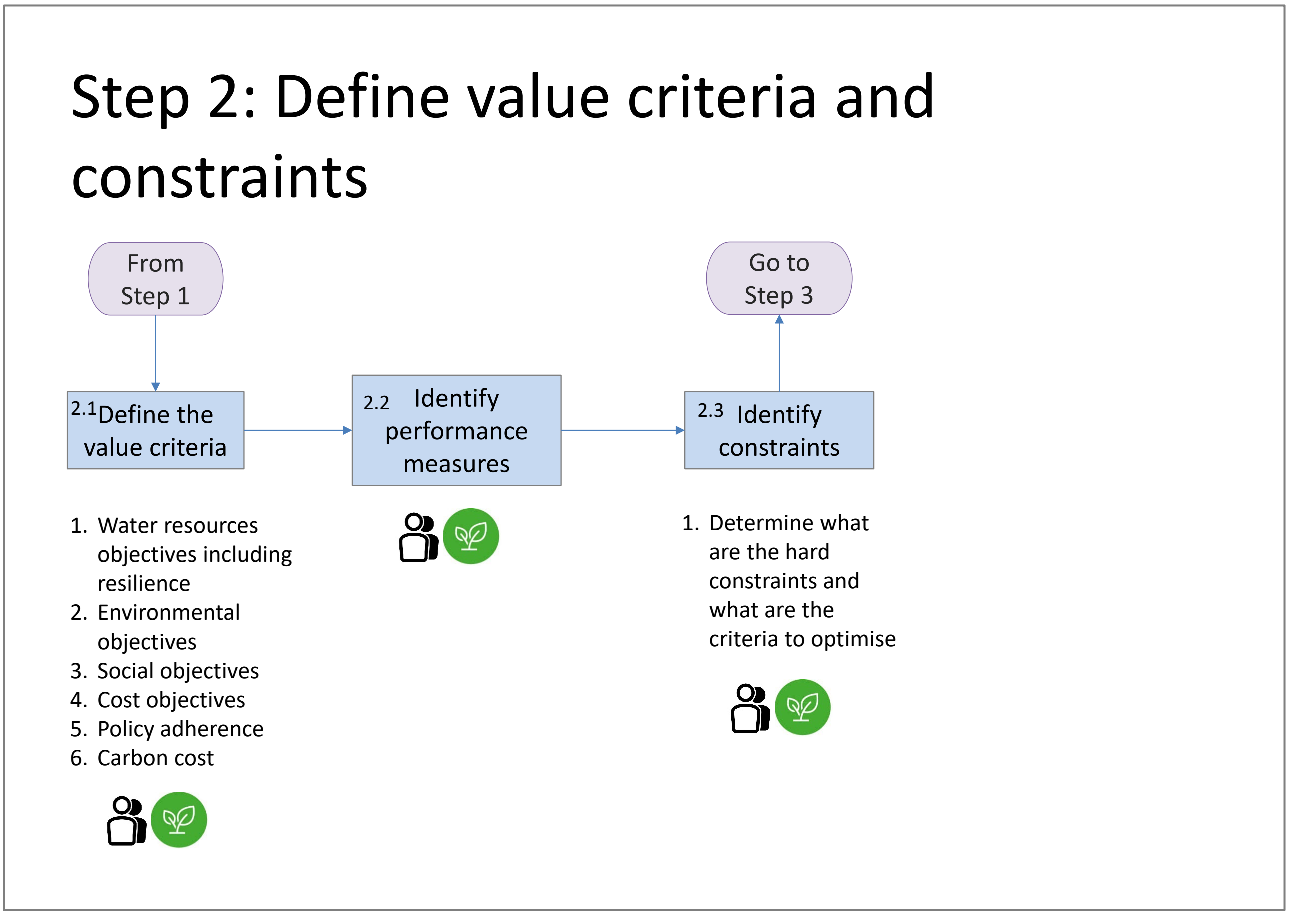

Figure 4.2: Step 2: Define value criteria (referred to as metrics by WRW) and constraints

Source: UKWIR (2020)

It is a requirement of the multi-criteria decision tool that it enables the consideration of several different types of metrics, since this is a fundamental concept in best value planning. WRW carried out a workshop for deciding on the metrics that would be used for the development of the Regional Plan. These metrics are listed in Table 4.1. Each of the water companies may use a different set of metrics for developing their company WRMPs. The tool will enable the water companies and WRW to include metrics that they choose to use in the MCDA process.

When determining the metrics that will be included within the MCDA model, it is essential that they fulfil the following properties (Belton and Stewart, 2001):

- Unambiguous: It is essential to have a clear relationship existing between consequences and descriptions using the metrics.
- Understandable: It is crucial that parties involved understand the consequences and value trade-offs.
- Direct: Levels of performance on the metrics need to directly describe the consequences of interest.
- Operational: The information to describe the consequences can be obtained and the value trade-offs can be reasonably made.
- Comprehensive: Levels of performance on the metrics' levels need to cover the range of possible consequences for the corresponding objective.

- Preferential Independence: How much one cares about the performance of an intervention on a metric should optimally not depend on its performance on other metrics.

In particular, in order to be able to use an additive aggregation within the multi-criteria decision tool, it is essential that the last property (preference independence) is satisfied. Failure to do so will lead to an MCDA that appears clear and well-founded, but that would generate spurious results as not a true reflection of the decision making group's understanding of the problem.

Table 4.1: WRW decision metrics

Ref.	Metric name	Description
1	Cost	Assessed by water companies. Total net present value (NPV) based on capital expenditure (CAPEX, initial and replacement) and operational expenditure (OPEX, fixed and variable).
2	PWS drought resilience	Assessed by water companies. Supply-demand balance change at 1 in 500 level.
3	Carbon costs	Assessed by water companies. Total NPV of monetised carbon costs.
4	Flood risk	Assessment from Strategic Environmental Assessment (SEA).
5	Human and social wellbeing	Assessment from SEA, covering health, human environment, social and economic wellbeing, cultural heritage, air quality assessments.
6	Sustainable natural resources	Assessment from SEA, Natural Capital Assessment (NCA) and Biodiversity Net Gain (BNG).
7	PWS customer supply resilience	Assessed by water companies. Customer valuations of willingness to pay (WTP) NPV, including supply interruptions, water quality, and water resources from SEA.
8	Multi-abstractor benefits	Assessment from SEA. Water quality and quantity, water resources.

Source: WRW (2020) Decision metrics supplementary note. Document 10a, v1.0 (16.06.2020).

The water companies will each need to identify the constraints for the decision making process, as in Task 2.3 of Figure 4.2. These constraints are included by setting a specific/minimum/maximum value for the performance measure of a metric that must be met. This could also include a date for the delivery of the benefit.

4.3. Step 3: Determine performance of alternatives against criteria (metrics)

Step 3 of the UKWIR (2020) BVP framework is to measure the performance of alternatives against the metrics identified in Step 2. The tasks involved in this step are shown in Figure 4.3. The water companies will need to carry out Tasks 3.1 to 3.9 prior to using the decision tool. Some further discussion of Task 3.8, generating plans for evaluation, is provided in Section 6.3.

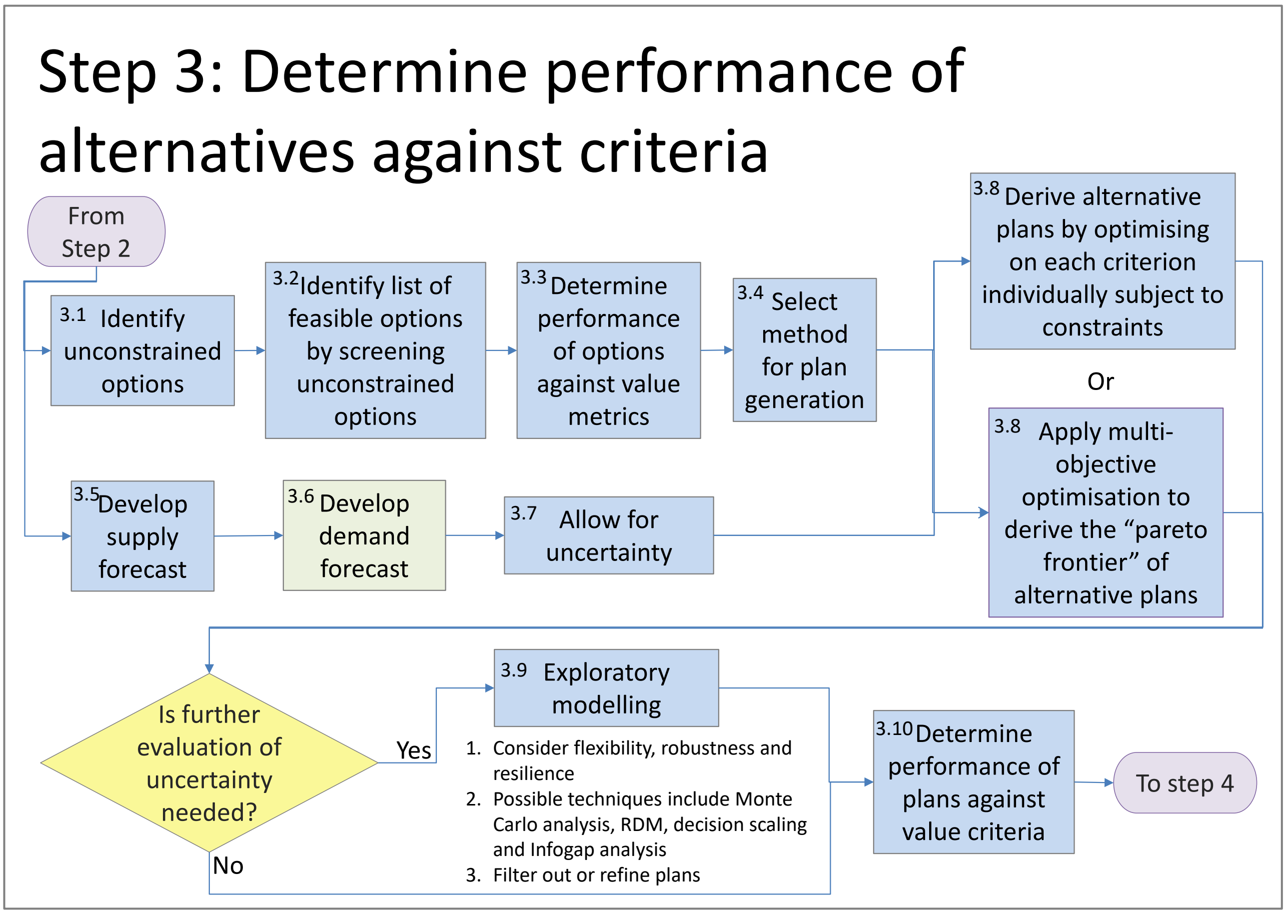

Figure 4.3: Step 3: determine the performance of alternatives against criteria (metrics)

Source: UKWIR (2020)

The measurement of the various metrics for WRW will not always be straightforward. Some of the metrics will be derived via the environmental assessment process (in a parallel study), including: Strategic Environmental Assessment (SEA), Natural Capital Assessment (NCA) and Biodiversity Net Gain Assessment (BNG). Other metrics will be quantified by assessments carried out by each water company.

Measuring SEA

Table 4.2 shows how the SEA objectives map on to the metrics to be included in the Regional Plan. Further details on the approach for the SEA are provided in Appendix B.

Table 4.2: Mapping of metrics to SEA objectives

Metric[3]	SEA objective	Performance measures (or attributes)
4. Flood risk	7. To reduce or manage flood risk	Qualitative assessment from SEA.
5 Human and social wellbeing	8. To minimise emissions of pollutant gases and particulates and enhance air quality.	Assessment from SEA, covering health, human environment, social and economic wellbeing, cultural heritage, air quality assessments.
	9. To reduce greenhouse gas emissions.	
	10. To adapt and improve resilience to the threats of climate change.	
	11. To protect and enhance human health and well-being.	
	12. To maintain and enhance tourism and recreation.	
	13. To promote a sustainable economy and maintain and enhance the economic and social well-being of local communities.	
	16. To conserve and enhance the historic environment including the significance of heritage assets and their settings and archaeological important sites.	
	17. To protect and enhance landscape and townscape character and visual amenity.	
6 Sustainable natural resources	1. To protect and enhance biodiversity, including designated sites of nature conservations interest and protected habitats and species, enhance ecosystem resilience and habitat connectivity and deliver a net biodiversity gain	Natural capital, biodiversity net gain and SEA environment (as per WRPG) – used in a way that can be substituted.
	2. To protect and enhance sustainable natural resources and the ecosystem services they provide.	
	3. To avoid and, where required, manage invasive and non-native species (INNS).	
	4. To protect and enhance soil quantity, quality and functionality and geodiversity and ensure the appropriate and efficient use of land.	
	15. To minimise waste, promote resource efficiency and move towards a circular economy.	

[3] These are the decision metrics as identified in the WRW document: 10a. Decision metrics supplementary note v1.0 (16.06.2020).pdf. These are referred to as value criteria in the UKWIR Best Value Plan Framework.

Metric[3]	SEA objective	Performance measures (or attributes)
8 Multi abstractor benefits	5. To protect and enhance surface and ground water levels and flows.	Water quality and quantity, and water resources from SEA.
	6. To protect and enhance the quality of surface and groundwater resources.	
	14. To promote and enhance the sustainable and efficient use of resilient water resources.	

Notes: The environmental assessment (SEA, NCA, BNG) metrics will each be measured with two metrics; one for positive effects and one for negative effects. This is to avoid the netting of positive and negative effects.

Deriving the SEA measurement will require a sub-step to be carried out which can be described as a sub-MCDA within the overall MCDA for the plans. For the metrics that combine more than one SEA objective (Metrics 5, 6 and 8), the SEA scores will need to be aggregated in order to give a combined score.

There is a balance between clarity and transparency in the MCDA process and avoiding the netting of effects as assessed in the SEA process. Through discussion with WRW and the SEA team, the following decisions have been agreed:

- For all SEA-based metrics (Metrics 4, 5, 6 and 8), both positive and negative impacts will be included as separate metrics in the MCDA process. This is because it is important not to net the positive and negative effects of an option and a plan.
- All other aspects from the SEA-based metrics (i.e. the multiple SEA objectives and the construction/operation effects, which we henceforth refer to as sub-metrics) will be aggregated within the MCDA metrics. This decision was made in order to avoid over-extending the set of metrics to be used at the weighting stage.

Where SEA scores are to be aggregated into a combined metric, the core requirement is that the weight of each metric should be relative to the range of impact that the metrics take relative to each other. The aggregation process for combining the SEA objectives and construction/operation effects thus needs to take into account judgements regarding how each of these aspects contributes to the combined metric. We will explore this in the workshop as explained in Appendix C.

A summary spreadsheet will need to be produced which includes the following data in tabular fashion:

- Effects table summarising the performance of the options against each SEA sub-metrics.
- A table summarising the weights against the SEA sub-metrics.
- A table summarising the scores of options against each SEA sub-metric (specifying how the performances have been converted into scores via excel formulas, such as v look ups).
- A table summarising the weighted scores of options against each SEA sub-metric and the overall aggregated score for each option.

Measuring non-SEA metrics

With regard to the non-SEA metrics, we anticipate the following approaches will be readily undertaken by companies to populate the MCDA tool.

1. **Metric 1: Cost**: this should be relatively straightforward to measure as a monetary value at the option and plan/programme levels.
2. **Metric 2: PWS drought resilience:** rather than measuring supply-demand balance change at 1 in 500 level, we would recommend that a monetary value be obtained for this value criterion at the plan/programme level using the spreadsheet model developed by FastTrack[2] for WRW. Companies should put together a short list of scenarios in terms of levels of service they want to test and optimise programmes on each of them. These may include altering the balance, for example, between Temporary Use Bans, Rota cuts and Non-Essential Use Bans as well as altering the levels of service on each.
3. **Metric 3: Carbon costs**: these should be calculated at the option level using Green Book/BEIS valuations plus UKWIR guidance. Plan/programme level carbon costs are then readily calculated by aggregating over the included options in the programme.
7. **Metric 7: PWS customer supply resilience**: a monetary value will be obtainable at the option level for this metric using the spreadsheet model developed by FastTrack[2]. Companies have all received the spreadsheet and will be able to use it directly to help them obtain this monetary measure. Plan/programme level values are then again readily calculated by aggregating over the included options in the programme.

Effects table

In Task 3.8 of the BVP framework, a range of programme alternatives will have been developed, and each one will have values assigned to each of the twelve metrics. (Originally there were eight, but four have been split into positive and negative metrics.) Each alternative plan's performance on a given metric must be assessed in the same way to ensure consistency of measurement. Once this has been done, it is helpful to organise the data in an effects table (or performance table), as in Table 4.3. Alternative approaches, such as parallel axis plots, can also help present the various outputs.

Table 4.3: Effects table – for illustrative purposes

Ref.	Metric name	Unit (scale)	Plan 1 (mean)	Plan 2 (mean)	Plan 3 (mean)	Min^	Max^
1	Cost	Economic valuation (£)					
2	PWS drought resilience	Economic valuation (£)					
3	Carbon costs	Economic valuation (£)					
4a	Flood risk – positive effects	Score or assessment					
4b	Flood risk – negative effects	Score or assessment					
5a	Human and social wellbeing – positive effects	Score or assessment					

Ref.	Metric name	Unit (scale)	Plan 1 (mean)	Plan 2 (mean)	Plan 3 (mean)	Min^	Max^
5b	Human and social wellbeing – negative effects	Score or assessment					
6a	Sustainable natural resources – positive effects	Score or assessment					
6b	Sustainable natural resources – negative effects	Score or assessment					
7	PWS customer supply resilience	Economic valuation (£)					
8a	Multi-abstractor benefits – positive effects	Score or assessment					
8b	Multi-abstractor benefits – negative effects	Score or assessment					

Source: Adapted from UKWIR (2020). Notes: Min^ and Max^ denote the range of outcomes between which the interventions perform.

5. Tool functionality and outputs (UKWIR BVP Steps 4 and 5)

5.1. Step 4: Determine scores and weights

Step 4 (see Figure 5.1) of the generic approach in the UKWIR (2020) best value plan framework is to determine scores and weights for the metrics.

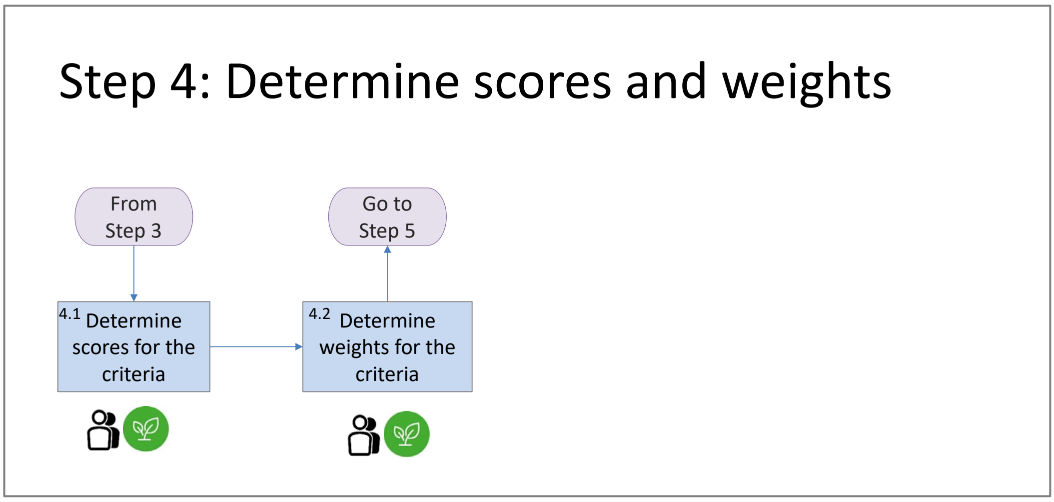

Figure 5.1: Step 4: Determine scores and weights

Source: UKWIR (2020). Note again that criteria in the UKWIR (2020) framework refers to the metrics in the WRW process.

Given that the MCDA considers different types of metrics, each requiring different types of units, each of these measurements will need to be converted into a common scale for the MCDA process. This scale is typically represented between 0 and 100, representing the worst possible and acceptable outcome/performance and the best possible and achievable outcome/performance respectively. Scores are used to determine how the different performances are valued, i.e. determine the relative value of changes within a criterion. These are also referred to as partial values, which can be displayed in a value function.

Subsequently, weights will be required to denote the relative value of performance changes on different metrics, or the trade-offs between metrics. The weights are a means to enable prioritising between the different metrics. In other words, they reflect how much we are willing to accept some disadvantages of a plan in order to get some of its other benefits. For example, how much additional financial cost are we willing to accept to obtain an increase in environmental benefit?

For each metric, it is necessary to provide a table or value function for converting the performance measure value to a value on the common scoring scale between 0 and 100. For continuous metrics, a value function will be needed. The shape of the value function will differ depending on the metric and the range. For relatively narrow ranges of performance, it might be a reasonable assumption to have a linear value function, but for larger ranges of performance, it is strongly recommended to check for the linearity of preferences.

A hypothetical example value function is provided in Figure 5.2 for illustrative purposes. In this example, the cost value function is depicted as a concave function, where the decision makers view an increase in £5M/year much worse towards the higher end of the range (60 to £65M/y is worth a drop of 25 points out of 100), than at the lower end of the scale, where an increase of £5M/year between £30 to £25M/y is worth a drop of 5 points only (see the red and green triangle in Figure 5.2).

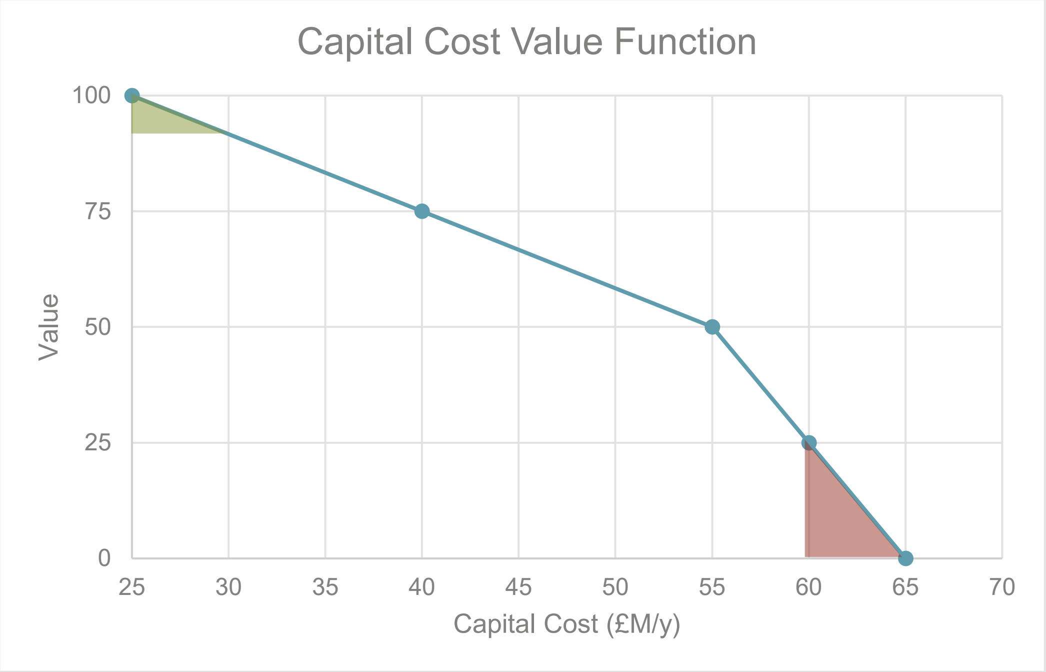

Figure 5.2: Hypothetical value function for Metric 1: cost

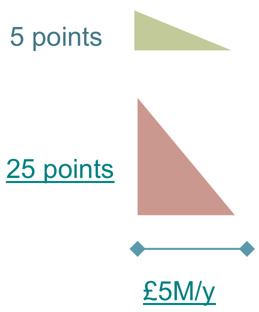

Figure 5.3: Graphical representation of difference in value for £5M/y

For discrete metrics, for those which the measures are a combination of qualitative and quantitative description for each level, this function will be depicted as in Figure 5.4. In this illustrative example, the increase from level 0 to level + is perceived much more (50 points) valuable than from level ++ to level +++ (20 points). These functions are likely to differ depending on the SEA metrics and potentially the zone where it applies.

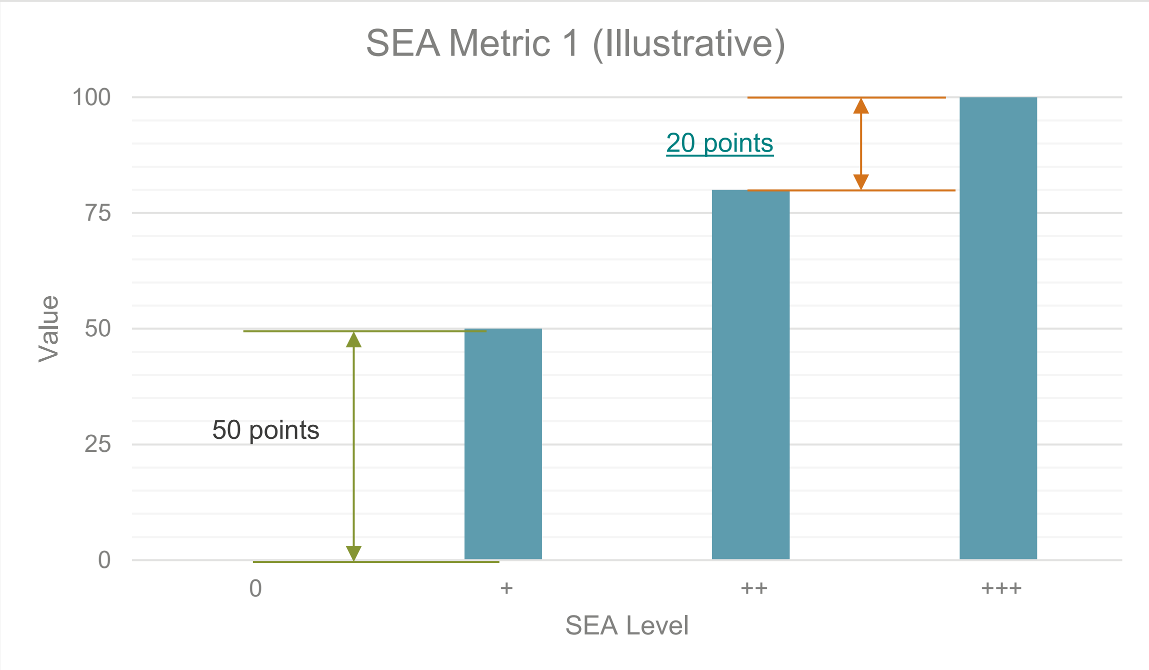

Figure 5.4: Hypothetical value function for a discrete metric (one of the SEA metrics)

The elicitation of these value functions can be done using the bisection method or MACBETH as described in Section 4.

The value functions or conversion tables will need to be developed through the WRW regional plan process to ensure that the score conversion captures how the WRW team wishes to value the performance of each metric. The decision making process to assign these value functions should be documented and the rationale for the decisions explained and justified.

As discussed in Section 4.3, the swing weighting method can be used to elicit the weights.

To ensure the validity of the judgements elicited, we will facilitate two workshops to develop the value functions and weights required for implementing the MCDA tool to develop the regional plan, which we discuss further in Appendix C.

5.2. Step 5: Evaluate and compare alternative plans

Step 5 of the generic approach in the UKWIR (2020) best value plan framework is to evaluate and compare alternative plans. The decision tool will provide the functionality to do Task 5.1 to assess the overall performance of the plan alternatives put forward from Step 3 by applying the Step 4 scores and weights. For each metric, its weight is multiplied by the score of a plan on that metric. The overall value of a plan is then calculated by adding the weighted scores together. This provides the results of the MCDA process.

A summary spreadsheet will need to be produced which includes the following data in tabular fashion:

- Effects table summarising the performance of the plans against each metrics.
- A table summarising the weights against the metrics.

- A table summarising the scores of options against each metrics (specifying how the performances have been converted into scores via excel formulas, such as v look ups).
- A table summarising the weighted scores of options against each metrics and the overall aggregated score for each plan.

The tool will then also enable Task 5.2 to be done, carrying out sensitivity analysis and stress testing which needs to be carried out to provide further depth to the results provided by aggregation of the data provided by the tool. This type of analysis provides a way to understand the extent to which vagueness about the preference inputs or disagreements between the participants make a difference to the overall value of the options, and their ranking.

Tasks 5.3 and 5.4 will then need to be carried out by water companies, to perform wider programme appraisal in order to select a preferred plan and consultation.

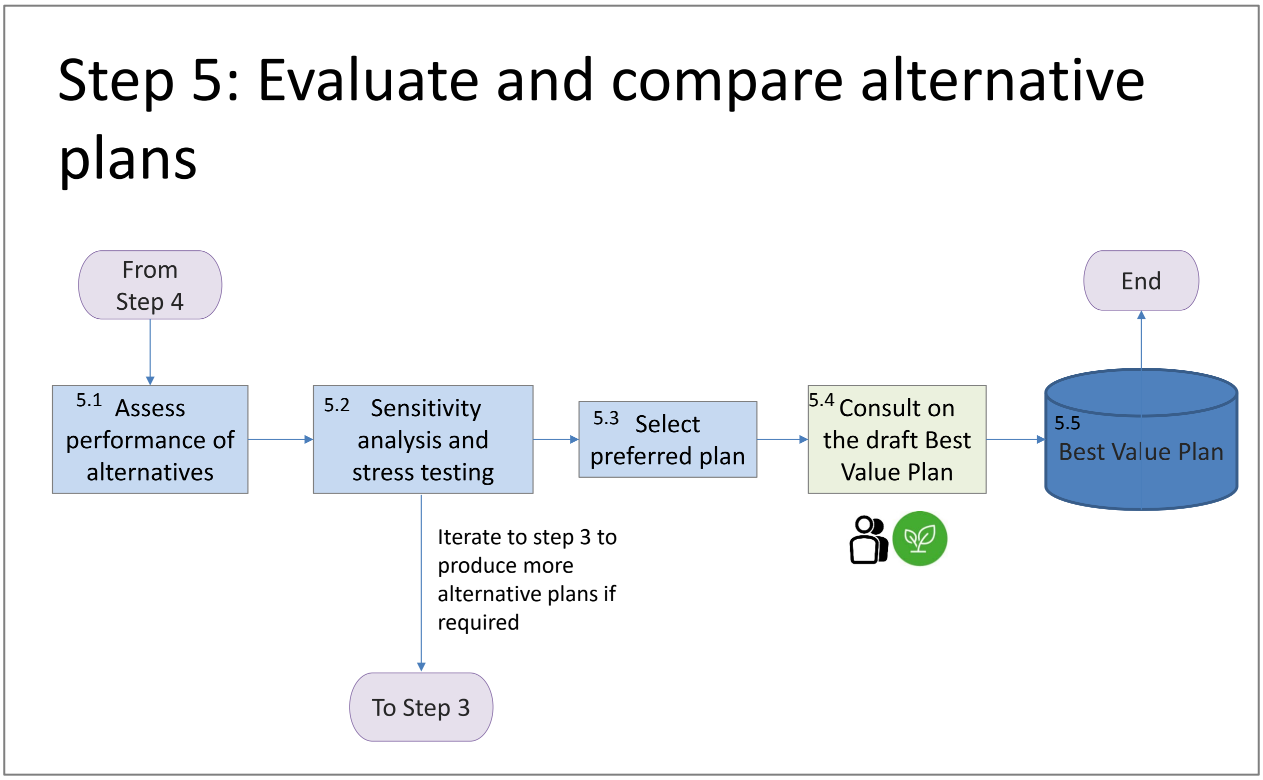

Figure 5.5: Step 5: Evaluate and compare alternative plans

Source: UKWIR (2020)

6. Further work

6.1. Overview

The work described in this section are activities that support the implementation of the decision tool.

6.2. Customer research

A core requirement for water resources planning is to be able to demonstrably and transparently obtain and utilise customer insight in order to produce a WRMP that genuinely reflects customer preferences. Although customer WTP evidence is already factored into the measurement of Metrics 1 and 7 (PWS drought resilience and PWS customer supply resilience), there is an absence of direct evidence on how customers would prefer to see the metrics weighted against one another. We would therefore recommend that companies consider conducting research to ensure that customer preferences are incorporated within the determination of the weights assigned to each of the metrics. This would be additional work to the scope previously set out for the decision tool.

Consistent with UKWIR (2020) BVP guidance, our recommendation would be for companies to conduct both qualitative and quantitative research for this purpose. The qualitative phase would introduce the metrics and the form that they might be presented in a quantitative survey, as attributes, intended to measure their relative value. Each attribute would need to be designed to correspond to a decision metric, but with the language and definition tailored to be understandable and meaningful to customers. The qualitative research would focus on exploring understanding of the metrics in order to help refine them, and also provide qualitative insight into the relative importance of the different metrics to add depth to the findings from the subsequent quantitative phase.

The purpose of the quantitative phase would then be to obtain measures of customers' decision weights with respect to the metrics entering the MCDA tool. We would anticipate a pairwise choice exercise being most appropriate for evaluating preferences between supply-demand solutions. Table 6.1 provides an illustration of the type of question we have in mind. The survey would benefit from including visually engaging material to communicate the solution option and its relative impacts on each of the key decision metrics.

Participants could be shown a sequence of option pairs and asked in each case which of the two they would prefer to see implemented in their region. The number of questions to be shown would depend on how many options were being evaluated. Each option should be seen at least once by each person but the order in which they appear, and the permutations of options within pairs, would be varied across the sample according to an experimental design.

The advantage to measuring value weights rather than, or as well as, preferences over solution options, is that customer preferences can be considered directly in terms of how much weight to put on the various decision metrics. There may be good reason why decision makers choose to adopt different weights to the weights derived directly from customers, for example due to their greater knowledge and understanding of the policy and operational context than customers. However, understanding how customers trade off these metrics against one another is a good way to ensure that their views are being appropriately reflected in the weights that are chosen.

In the absence of customer research of this kind being conducted, it will still be possible for decision makers to use the multi-criteria decision tool, and they may consider the insights they have from existing sources to help them do so. However, the weighting in this case will be less likely to correspond as closely to customer preferences as would be the case were the suggested research undertaken.

Table 6.1: Illustrative example of customer consultation question

	Option A	Option B
Frequency of temporary use bans	1 in 10 years (same as now)	1 in 15 years (better than now)
Carbon emissions	- Negative	+ - Positive
Flood risk	Neutral	Neutral
Human and social wellbeing	+ Positive	Neutral
Impact on rivers	+ Positive	Neutral
How many properties experience a supply interruption in any one year	1 in 50 (same as now)	1 in 75 (better than now)
Change in your annual bill from 2023	Increase by £2	Increase by £1
Which option do you prefer?	○	○

In all cases water quality meets all legal standards

6.3. Generating plans and determining performance against metrics

The decision tool will provide a simple approach for optimising options to generate plans and determine performance against metrics. We recommend a more sophisticated approach be developed over the next year in order to provide a more complete exploration of the possible range of plans that can be generated.

One possible approach for doing this is a pareto optimisation approach, that will enable generating portfolio of plans on several metrics. This could take the form of an a priori-multi objective technique based on the ε-Constraint Method. In this method, In the ε-constrained objective is maximized (or minimized) subject to lower/upper limits on the other objectives. In each pareto run, the constraints are modified to trace out the pareto frontier, see Figure 6.1.

The user can control the number of generated pareto efficient plans by adjusting the number of grid point[4] for each objective function ranges.

[4] Grid point: When dividing the ranges of the objective functions in n equal intervals and obtain n+1 grid points.

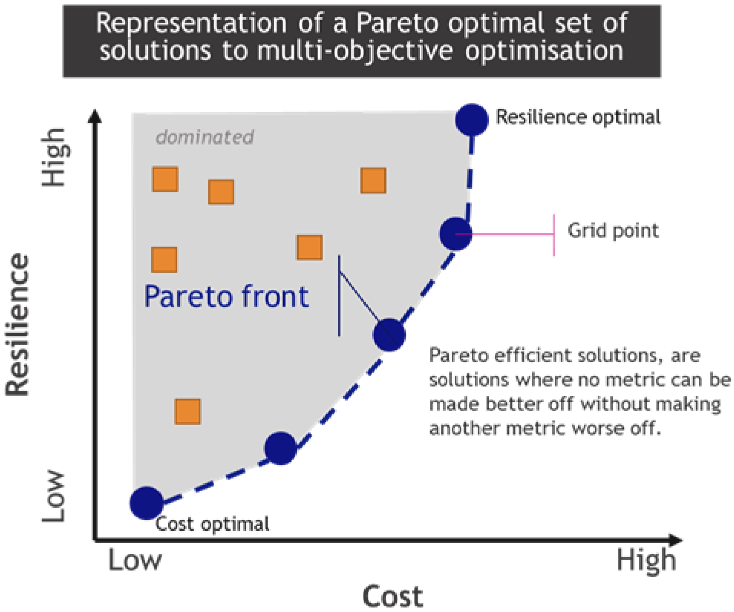

Figure 6.1: Representation of a pareto optimal set of solutions to multi-objective optimisation

This approach consists of two steps:

- Step 1 involves identifying the solution space, (e.g. identify ranges for each metric (objective)).
- Step 2: involves specify number of pareto solutions for each metric (e.g. grid points). Then multiple bi-objective (trade-off) runs will be conducted to identify pareto optimal plans. In each run one metric will be kept in the objective function while we constraint another target metric in order to explore the pareto frontier. It is proposed that in all runs we use a least-cost objective function, while we subsequently change the constrained preference metric.

The optimisation model will generate portfolio of plans, including their performance on the metrics used. These will be summarised in an effects table as in Table 4.3. It is possible that not all metrics will have been included within the optimisation, and in this case, the water companies will need to manually complete the effects table by adding the performance of the generated plans on the missing metrics by looking at the options that the generated plan includes.

7. Conclusion

It is a regulatory requirement that water companies and regional organisations develop “best value” plans for managing water resources. The UKWIR (2020) framework for best value water resources management plans sets out a multi-criteria decision analysis (MCDA) approach for developing a best value plan. It is proposed in this specification note that the multi-criteria decision tool follows the MCDA approach set out in the UKWIR (2020) BVP framework.

We propose to develop the decision tool in Excel and VBA to meet the preferences of the water companies. The benefits of having a tool in Excel include the familiarity of users with using Excel and the ability for users to see the equations that are behind the calculations.

Appendix C of the report sets out the steps for developing the decision tool.

8. References

Belton and Stewart (2001) Multiple Criteria Decision Analysis - An Integrated Approach. Boston, MA: Kluwer Academic Publishers.

UKWIR (2020) *Deriving a best value Water Resources Management Plan.* UKWIR Report. Authors: Adamson, J., Ball, A., Blaxland, A., Gkolemi, I., Holbrook, J., Houlden, V., Metcalfe, P., Moylan, C., Simpson, M., Sri Bhashyam, S.

Water Resources West (WRW) (2020) *Decision metrics supplementary note.* Document 10a, v1.0 (16.06.2020).

Appendices

A. Findings from interviews with water companies

Table A.1: Interview responses from UU

UU	Question	Response	Action
A. MCDA tool/approach			
A1.	What were your MCDA tool/approaches for WRMP19?	There are technical appendices for this (e.g. option appraisal, decision making, customer research) and UU is going to share those with us. There are 10-20 customer research elements that are fed into the decision-making process.	UU to send relevant reports and slide packs
A2.	What constraints did you include in your MCDA modelling? PCC, leakage, budget, etc? Where are you currently in terms of meeting the 50% leakage reduction target? Are you trying to meet it in regional level or water company level?	A lot of work around water trading but this was not included in the EBSD or MCDA. UU used a system simulation approach were they simulated many optimal solutions given by EBSD to identify the best portfolio. The system simulation approach (run through a water resource model) had about 15-20 metrics. Regarding leakage reduction and other similar targets, they were considered and met at a water company level not regional.	
A3.	What criteria do you currently use, and/or you think must be included in the model? Certain water companies will have challenges others do not have, can you elaborate on your challenges that should be reflected in a criteria and relevant metric? What criteria do you have that are inter-regional or inter-company?	UU already has similar spreadsheet like those used by WRSE decision-making process. If HR Wallingford shares with them a template or spreadsheets with dummy data, UU will be able to provide a list of criteria and the associated information that should be used in the project. UU would like to be able to include their own metrics, in addition to the 8 metrics mention in the ITT document.	HR Wallingford to share with UU a template for spreadsheets needed to collect information around UU's criteria
A4.	For the above criteria, what unit you're using for the measurement? For example, leakage reduction can be expressed in Ml/d or l/p/d or l/Km.	Everything for UU is in Ml/d. UU will provide the right unit anyway.	

UU	Question	Response	Action
A5.	What options (interventions/investment decisions) did you use for your WRMP19 decision-making?	UU will provide these.	UU to provide a list of options in a spreadsheet.
A6.	For WRMP19, how did you elicit values and priorities (e.g. weights and value functions) and who did you contact?	UU didn't use weights as such. They had a set of primary metrics and a set of secondary metrics. For example, if they consider water trading, they want to protect customers, environment, etc. (perhaps by minimising harm to those)-so they will chose the metrics that represents this. In doing so, after selecting the trade option, they will calculate the performance of the system for environment, customer, etc. Then they will modify the option so that the performance against the above metric gets close to the expected level.	UU to share the tables (s) containing their primary and secondary metrics
A7.	How did you quantify the performance of different plans? Did this come out of your EBSD model, if so how?	This was done within the system simulation part of the decision making process, not within the EBSD model. For example, when considering the water trading option, they calculated metrics such as frequency of customer experiencing restrictions or frequency of reservoir spillage or breaching HOF conditions. In summary, UU ran many number of simulation and chose among them the best performing portfolios based on the metric scores.	
A8.	How did you include supply-demand balance within in your MCDA tool (e.g. look up table, a simple Excel spreadsheet, etc.)?		UU to share SD balance spreadsheet
A9.	How did you deal with uncertainty surrounding the performance of plans in your MCDA modelling? e.g. have you carried out a probabilistic sensitivity analysis, or scenario planning to deal with uncertainty?	The only uncertainty source that was considered was climate-related ones. Options were tested against many different climate scenarios to account for uncertainties and to make sure they are robust under extreme climates. No uncertainty around the options and how they perform was included. Although, there was a screening stage where options that are not certain did not enter the decision-making process.	

UU	Question	Response	Action
A10.	How did you deal with uncertainty surrounding the values and priorities elicited from participants (if you've carried out this task in WRMP19)?	Since UU didn't use weights explicitly, there is no uncertainty around weights.	
A11.	Do you already have in mind particular visual outputs and/or particular visual requirements for the MCDA ?	UU would like to use weights and be able to see the trade-offs by changing the weights, and what these trade-offs mean in terms of what portfolios are selected and its impact on the wider system. UU would like to see the impact of different metrics such as the impact on the leakage and PCC over time. Also, comparing the impact of longer-term options with the shorter-term ones, specifically for leakage.	
A12.	Following the assurance process for WRMP19, was there any particular recommendations from stakeholder groups/water companies that might be relevant to this project and we have to incorporate?	There has been consultation with stakeholders to elicit metrics and score.	
B. EBSD modelling			
B1.	How did your carry out EBSD modelling for WRMP19?	UU used a fairly standard EBSD approach where they were optimising based on AISC. Within this EBSD model there are criteria such as environmental or social costs. The EBSD model was also used to determine scheduling of options.	UU to share the EBSD spreadsheet and any relevant document explaining the process
B2.	What type of environment did you use for solving your EBSD problem? Was it developed in Excel, in a mathematical modelling tool like AIMMS or GAMS or was it developed in Python (or another programming language)?	Excel spreadsheet.	

UU	Question	Response	Action
B3.	Provide a brief description of your WRMP19 EBSD model inputs – outputs and their format.	The EBSD spreadsheet model will explain this.	
B4.	What physical/asset constraints did you use in your EBSD modelling?	See above.	
B5.	Do you rely on your current EBSD tool to determine scheduling of options or is it the MCDA tool that obtains this?	EBSD model does the scheduling.	
B6.	What are your current model runtimes?	It runs over night but is dependent on the number of options input to the model.	
B7.	How does your model handle supply deficit?	The model minimises the deficit, if any.	
B8.	Did your model include metrics other than “least” cost (e.g. environmental benefit, resilience etc.)? If yes provide a brief list of the metrics with descriptions.	AISC which includes monetised environmental and social costs. The cost is also based on capex, opex, carbon cost and DNS. Social cost, for example, includes recreational cost and environmental cost includes carbon cost. But they are all monetised eventually.	UU to send the report that shows how environmental and social costs are calculated
B9.	Does your model support any type of multi-objective optimisation that allows exploration of portfolio of options that score good in different monetised and non-monetised performance metrics?	The current EBSD tool monetises all the objective functions and adds them together with equal weights and optimises them in one go. There is no capability to run multi-objective optimisation and getting a Pareto trade-off as an output.	
C. Customer research/engagement			
C1.	What were the key customer engagement studies you relied on for WRMP19?	There are technical reports and slide packs explaining these.	UU to share these documents
C2.	Please can you share the original reports from these studies?	See the above.	

UU	Question	Response	Action
C3.	How did you incorporate customer preferences in your WRMP19? Please be as detailed as possible; for example, did you formally incorporate measures such as willingness to pay, or priority scores, in an MCDA tool, or within your EBSD modelling? Did key decisions hinge on customer evidence? Or did you informally refer to customer evidence as a cross-check / validation of the outcomes of your WRMP process?	The willingness-to-pay metrics are included in the EBSD model and AISC calculation which can be optimised on. Customer preferences influence the option choice but in a rather manual way. Willingness-to-pay is also used to inform supply demand balance. For example if there is willingness to pay for improving the level of service, then UU works out the supply demand balance to solve.	
C4.	Can you share with us any document that are not on public domain, concerning how customers preferences were incorporated within WRMP19?		UU to share these documents
C5.	For WRMP24, WRW commissioned the FastTrack2 report 'Analysis of customer valuations for regional plan – WRW companies'. Is there a plan already in place concerning how this evidence is to be used?	Richard shared a report for this UU. The essence of Frank's work is taking companies' costumer valuation from WRMP19 and translate them into regional customer valuation.	HR Wallingford to ask Richard to share this report
C6.	Are there any other plans in place regarding how customer evidence is to be used for WRMP24, or is it entirely up to us to develop recommendations in this regard?	There are plans in place. There is also a work around costumer engagement. It is not entirely up to the project team but UU would like to see what we recommend about costumer research/engagement and the link to Frank's work.	
D. Uncertainty/risks			

UU	Question	Response	Action
D1.	How do you take into account hydrological uncertainty in your decision-making process?	They run the system simulation approach under lots of stochastic droughts and lots of climate change scenarios and different demand levels. UU mainly uses target headroom in the EBSD model to account for uncertainty. UU's focus in on 1 in 500 years scenario. An alternative is to use a return period for the first part of the planning horizon and a different return period for the remainder. They don't envisage using multiple different return periods like in the WRSE project.	
D2.	How do you include decision-making related (non-hydrological) uncertainties within the MCDA tool? A single best value plan might not be robust against unforeseen incidents.	UU doesn't use uncertainty on the options but only on its supply (e.g. climate change) and demand (e.g. meter error) which are included in the form of target headroom.	
D3.	What risks (around security, budget, time, modelling approach, etc.) do you envisage for your decision-making process in this project?	Any data/information that goes into WRMP is fine to be shared with others. But sharing any other data/information (e.g. cost of options) will breach competition law. Also, UU has a policy around where data can be stored.	UU to consult with their IT team to further identify any security issue that might arise for this project
E. Implementation and IT issues			
E1.	Do you prefer the new MCDA tool to be developed as an Excel workbook or a web portal?	UU prefers Excel because with the web portal you cannot see the underlying code.	UU to conform this
E2.	Does your company IT policy allow running VBA Macro within Excel files?	Yes.	
E3.	If we opt for a web portal, what IT issues might arise that we have to be aware of?	N/A	

Table A.2: Interview responses from STWL

STWL	Question	Response	Action
A. MCDA tool/approach			
A1.	What were your MCDA tool/approaches for WRMP19?	STWL didn't explicitly use an MCDA tool for WRMP19, it was done implicit within their modelling. They have a model (started using around 2004) that incorporates water distribution and mains + water supply-demand investment/intervention programme. The reason for using such approach was to reflect the true economic extent of leakage and mains renewal captured via a set of least-cost economic supply-demand interventions. STWL tested multiple future supply-demand balance scenarios using a model to come up with least-cost mains interventions options that help them achieve the leakage ambition. They layered on top of that, thousands of climate and environmental scenarios. from that, they carried out probability investigation into seeing which solutions were picked up in the majority of future scenarios. This helped them identify investment decisions based on their likelihood to appear in future scenarios. STWL didn't use other metrics such as natural capital biodiversity gains, however, the selected options went under SEA scrutiny as a post-process stage. So, they were able to show options that can deliver SEA objectives as well. For WRMP24, STWL still wants to use their core supply-demand model and investment model, but they also want a second stage optimisation to be built and added to their model (WiSDM). This second stage optimisation would be a MCDA tool that determines scores of different programmes against a number of metrics (e.g. biodiversity, natural capital, etc.) and optimally selects from thousands of nearly optimal options, those that score best. At the end of this process, STWL will have	

STWL	Question	Response	Action
		a portfolio of options that scores best against individual metrics or netted metrics.	
A2.	What constraints did you include in your MCDA modelling? PCC, leakage, budget, etc? Where are you currently in terms of meeting the 50% leakage reduction target? Are you trying to meet it in regional level or water company level?	e.g. prevent deterioration from mains burst, prevent customer supply interruption, improving performance on burst frequency. All the targets were a company target. However, to meet the target at the company level, they weighted their 15 WRZ based on their size to achieve for example the 50% leakage reduction in total.	
A3.	What criteria do you currently use, and/or you think must be included in the model? Certain water companies will have challenges others do not have, can you elaborate on your challenges that should be reflected in a criteria and relevant metric? What criteria do you have that are inter-regional or inter-company?	It is possible to add other metrics, but STWL has no insight at the moment about it at this stage.	STWL to check how they can share with HR Wallingford sensitive information such as cost breakdown of options.
A4.	For the above criteria, what unit you're using for the measurement? For example, leakage reduction can be expressed in Ml/d or l/p/d or l/Km.	Ml/d	
A5.	What options (interventions/investment decisions) did you use for your WRMP19 decision-making?	These can be found on public domain.	
A6.	For WRMP19, how did you elicit values and priorities (e.g. weights and value functions) and who did you contact?	The weights for 9 different metrics came from customer research that STWL undertook - what customers value the most (e.g. jobs created, biodiversity net gain). However, this wasn't used for WRMP19 and decision-making process but for the green recovery assessment. For	STWL to share documents that explains these (preference on different

STWL	Question	Response	Action
		WRMP19, STWL didn't use any weight for metrics as they didn't carry out an MCDA approach explicitly.	options, values of change in level of service, etc.)
A7.	How did you quantify the performance of different plans? Did this come out of your EBSD model, if so how?	It is done inside the WISDM tool. It is done in two stages: a pipe intervention model (looks at leakage performance etc.) which determines the optimal way of offsetting leakage deterioration to achieve the long-term leakage target; and a second stage layered on top of that is running 6000 supply-demand futures which reflects different climate, growth, and environmental conditions, to test the scheduling and optimal sequence of options.	
A8.	How did you include supply-demand balance within in your MCDA tool (e.g. look up table, a simple Excel spreadsheet, etc.)?	STWL used a system simulation model called Aquator to derive the DO for those 6000 future scenarios. This is transformed into a look-up table containing annual values of demand forecast, supply forecast, target headroom, and all of the options available for each WRZ. This table is then used by the WISDM model.	
A9.	How did you deal with uncertainty surrounding the performance of plans in your MCDA modelling? e.g. have you carried out a probabilistic sensitivity analysis, or scenario planning to deal with uncertainty?	Every single option has uncertainty distribution around cost, benefits, and the time needed to deliver/implement. Lots of optimisation runs using future scenarios evaluates uncertainty around these decision points. This will lead to observing how frequently a scheme is picked among those future scenarios (similar to Monte Carlo analysis).	
A10.	How did you deal with uncertainty surrounding the values and priorities elicited from participants (if you've carried out this task in WRMP19)?	STWL didn't explicitly use any weight for the purpose of WRMP19 decision-making work. However, they did obtain some weights for the Green Recovery business case and are keen to see if they can be used in the context of WRMP24 decision-making process.	
A11.	Do you already have in mind particular visual outputs and/or particular visual requirements for the MCDA ?	No immediate preference at this stage. Although the Green Recovery work has produced some visualisation of outputs and it would be beneficial to align the visualisation of MCDA results with this.	STWL to share example of visualisation from the Green Recovery work

STWL	Question	Response	Action
A12.	Following the assurance process for WRMP19, was there any particular recommendations from stakeholder groups/water companies that might be relevant to this project and we have to incorporate?	STWL had a conversation with Ofwat and RAPID to discuss the draft method they are using for decision making process. How is STWL going to demonstrate the best value decision making as opposed to the least cost plan.	STWL to share relevant documents.
B. EBSD modelling			
B1.	How did your carry out EBSD modelling for WRMP19?	STWL uses their own model called WiSDM to give a set of nearly optimal least-cost options (e.g. network interventions, supply options, demand management, etc.). A technical document has been shared that describes how WiSDM works.	
B2.	What type of environment did you use for solving your EBSD problem? Was it developed in Excel, in a mathematical modelling tool like AIMMS or GAMS or was it developed in Python (or another programming language)?	A web portal. Underneath is a Genetic Algorithm developed by Arcadis.	
B3.	Provide a brief description of your WRMP19 EBSD model inputs – outputs and their format.	The document on WISDM explains this.	
B4.	What physical/asset constraints did you use in your EBSD modelling?	Most of these constraints are implemented within Aquator which generates supply-demand balance. The WISDM model tries to see how we can get supply to be equal demand in a least-cost manner using the list of available options (WISDM is the EBSD model with extra features and functionality).	

STWL	Question	Response	Action
B5.	Do you rely on your current EBSD tool to determine scheduling of options or is it the MCDA tool that obtains this?	It is done within the WISDM model.	
B6.	What are your current model runtimes?	If the model is supposed to optimise absolutely everything, it will take couple of days to run for the whole water company area.	
B7.	How does your model handle supply deficit?	The WISDM model has to solve also for deficits, what options can be selected to close the gap between the supply and demand forecast (generated by Aquator).	
B8.	Did your model include metrics other than "least" cost (e.g. environmental benefit, resilience etc.)? If yes provide a brief list of the metrics with descriptions.	Capex + Opex + Carbon cost was used in the WISDM model. The other metrics (environmental, resilience, etc.) were calculated and tested in thousands of scenarios as secondary stage to the WISDM modelling. STWL did monetise other metrics for WRMP19 but they should not be monetised for WRMP24.	
B9.	Does your model support any type of multi-objective optimisation that allows exploration of portfolio of options that score good in different monetised and non-monetised performance metrics?	Yes, STWL is working with Arcadis to finish adding this functionality into the WISDM model.	
C. Customer research/engagement			
C1.	What were the key customer engagement studies you relied on for WRMP19?		
C2.	Please can you share the original reports from these studies?	There is a technical appendix from WRMP19 that describes this.	STWL to send this through
C3.	How did you incorporate customer preferences in your WRMP19? Please be as detailed as possible; for example, did you formally incorporate measures	See above.	

STWL	Question	Response	Action
	such as willingness to pay, or priority scores, in an MCDA tool, or within your EBSD modelling? Did key decisions hinge on customer evidence? Or did you informally refer to customer evidence as a cross-check / validation of the outcomes of your WRMP process?		
C4.	Can you share with us any document that are not on public domain, concerning how customers preferences were incorporated within WRMP19?		STWL to share these
C5.	For WRMP24, WRW commissioned the FastTrack2 report ‘Analysis of customer valuations for regional plan – WRW companies’. Is there a plan already in place concerning how this evidence is to be used?	A report has been circulated by Richard Blackwell within WRW companies.	STWL to double-check with Richard to see if we can have access to that report
C6.	Are there any other plans in place regarding how customer evidence is to be used for WRMP24, or is it entirely up to us to develop recommendations in this regard?	There is a specific costumer engagement consultation workstream that focuses on what the evidences are and how they are going to be use. It is best to discuss this question with Richard Blackwell.	
D. Uncertainty/risks			
D1.	How do you take into account hydrological uncertainty in your decision-making process?	See response to A7.	

STWL	Question	Response	Action
D2.	How do you include decision-making related (non-hydrological) uncertainties within the MCDA tool? A single best value plan might not be robust against unforeseen incidents.	There are three key information attached to each option: cost, benefit, and how long it takes to be built and switched on. The WISDM model includes an uncertainty range around each of these, and following a Monte Carlo analysis the model captures these uncertainties.	There is a document that explains these - STWL to share it
D3.	What risks (around security, budget, time, modelling approach, etc.) do you envisage for your decision-making process in this project?	Data on cost of options is sensitive and must not be shared with other companies. Accessing people and data is another challenge for the project.	
E. Implementation and IT issues			
E1.	Do you prefer the new MCDA tool to be developed as an Excel workbook or a web portal?	There is no strong preference at the moment. STWL is looking for a tool/approach that provides scores and weightings to be fed into the WISDM optimisation model.	
E2.	Does your company IT policy allow running VBA Macro within Excel files?	STWL is using Office 365, so any new Excel plug-in will take time to make operational.	
E3.	If we opt for a web portal, what IT issues might arise that we have to be aware of?		

Table A.3: Interview responses from DCWW

DCWW	Question	Response	Action
A. MCDA tool/approach			
A1.	What were your MCDA tool/approaches for WRMP19?	The process was done in two steps. The first step is running the EBSD model to get a list of least cost solutions. The second stage includes environmental appraisal to understand the performance of different schemes against a set of metrics and to obtain the preferred plan.	
A2.	What constraints did you include in your MCDA modelling? PCC, leakage, budget, etc? Where are you currently in terms of meeting the 50% leakage reduction target? Are you trying to meet it in regional level or water company level?	Leakage reduction target was met at company level for WRMP19.	
A3.	What criteria do you currently use, and/or you think must be included in the model? Certain water companies will have challenges others do not have, can you elaborate on your challenges that should be reflected in a criteria and relevant metric? What criteria do you have that are inter-regional or inter-company?	It will be the set of 8 metrics indicated in the project ITT documents. However, there might be a number of Wales-specific metrics that are set out by the Welsh government.	DCWW to confirm if there is any additional metric that should be included. Also, DCWW to share Welsh government's guidance principles document that was used for WRMP19.
A4.	For the above criteria, what unit you're using for the measurement? For example, leakage reduction can be expressed in Ml/d or l/p/d or l/Km.	All measurements in Ml/d	

DCWW	Question	Response	Action
A5.	What options (interventions/investment decisions) did you use for your WRMP19 decision-making?	DecisionLab has the initial list of options. However, it was later updated.	DCWW to share the update list of options
A6.	For WRMP19, how did you elicit values and priorities (e.g. weights and value functions) and who did you contact?	All metrics monetised, no weighting applied	
A7.	How did you quantify the performance of different plans? Did this come out of your EBSD model, if so how?	Plans based on best value through monetised metrics within the EBSD model. For example, the carbon emission from an option (in tonnes) was calculated by DCWW engineering team and then translated into carbon cost by dLab.	
A8.	How did you include supply-demand balance within in your MCDA tool (e.g. look up table, a simple Excel spreadsheet, etc.)?	Excel entry of DO, demand, wafu, headroom	
A9.	How did you deal with uncertainty surrounding the performance of plans in your MCDA modelling? e.g. have you carried out a probabilistic sensitivity analysis, or scenario planning to deal with uncertainty?	All uncertainties dealt with at input stage through headroom within SDB, sensitivity managed through glidepath and components analysis.	
A10.	How did you deal with uncertainty surrounding the values and priorities elicited from participants (if you've carried out this task in WRMP19)?	No weight was explicitly used. Customer's willingness-to-pay was	

DCWW	Question	Response	Action
		not used in WRMP19 too.	
A11.	Do you already have in mind particular visual outputs and/or particular visual requirements for the MCDA ?	Not at this stage	
A12.	Following the assurance process for WRMP19, was there any particular recommendations from stakeholder groups/water companies that might be relevant to this project and we have to incorporate?	No specific feedback/recommendation.	
B. EBSD modelling			
B1.	How did your carry out EBSD modelling for WRMP19?	Decision lab tool	
B2.	What type of environment did you use for solving your EBSD problem? Was it developed in Excel, in a mathematical modelling tool like AIMMS or GAMS or was it developed in Python (or another programming language)?	AIMMS based	
B3.	Provide a brief description of your WRMP19 EBSD model inputs – outputs and their format.	Input in excel spreadsheet - Output in Decision lab software	
B4.	What physical/asset constraints did you use in your EBSD modelling?	Mutually inclusive/exclusive options	
B5.	Do you rely on your current EBSD tool to determine scheduling of options or is it the MCDA tool that obtains this?	Scheduling entered into input sheet	
B6.	What are your current model runtimes?	Very short, around couple of minutes if all options were fed into the model	
B7.	How does your model handle supply deficit?	Notification of unresolved deficit and its year. Then by adding options to close that gap. For example, if there is 10 Ml of deficit in	

DCWW	Question	Response	Action
		the system and there is only one option left which can produce up to 9 Ml, the model adds this option and ends the EBSD modelling with 1 Ml of deficit (rather than falling over because of not being able to fully resolve the deficit).	
B8.	Did your model include metrics other than "least" cost (e.g. environmental benefit, resilience etc.)? If yes provide a brief list of the metrics with descriptions.	Metrics all monetised (carbon cost worked out within tool). Constrained by timing of planning/construction. The guidance in Wales says that water companies must not monetise environmental and social benefits and it has to be done qualitatively. Therefore, these are dealt within the second stage scenario analysis.	
B9.	Does your model support any type of multi-objective optimisation that allows exploration of portfolio of options that score good in different monetised and non-monetised performance metrics?	All metrics monetised with linear solver, no capacity	

DCWW	Question	Response	Action
		to handle multi-objective optimisation.	
C. Customer research/engagement			
C1.	What were the key customer engagement studies you relied on for WRMP19?	Survey done via forum and survey questionnaire during WRMP19 planning period	
C2.	Please can you share the original reports from these studies?	Some info is available in WTP report	DCWW to share this report
C3.	How did you incorporate customer preferences in your WRMP19? Please be as detailed as possible; for example, did you formally incorporate measures such as willingness to pay, or priority scores, in an MCDA tool, or within your EBSD modelling? Did key decisions hinge on customer evidence? Or did you informally refer to customer evidence as a cross-check / validation of the outcomes of your WRMP process?	Customer evidence indicated preference for increased resilience and progressive metering which is in line with DCWW planning process. DCWW informally referred to customer evidence as a cross-check/validation of the outcomes of the WRMP19 process.	
C4.	Can you share with us any document that are not on public domain, concerning how customers preferences were incorporated within WRMP19?	No document outside public domain is available	
C5.	For WRMP24, WRW commissioned the FastTrack2 report 'Analysis of customer valuations for regional plan – WRW companies'. Is there a plan already in place concerning how this evidence is to be used?	Not as yet, better to discuss this with Richard Blackwell.	
C6.	Are there any other plans in place regarding how customer evidence is to be used for WRMP24, or is it entirely up to us to develop recommendations in this regard?	At present, DCWW is working with WRW	

DCWW	Question	Response	Action
		comms team to develop how to use WTP studies in WRMP24. There is also a consultation between Ofwat and water companies around the wider customer engagement and how it should be incorporated in price review 24.	
D. Uncertainty/risks			
D1.	How do you take into account hydrological uncertainty in your decision-making process?	Uncertainty is managed through the application of headroom figures to the SDB, via component S6-1 of the headroom (S means a supply side component). Scenario testing was done using multiple stochastic scenario.	
D2.	How do you include decision-making related (non-hydrological) uncertainties within the MCDA tool? A single best value plan might not be robust against unforeseen incidents.	Through headroom and glidepath selection as well as probabilistic outage figures which takes account of uncertainties around	

DCWW	Question	Response	Action
		options and their performance.	
D3.	What risks (around security, budget, time, modelling approach, etc.) do you envisage for your decision-making process in this project?	Management of data and information across different stakeholders.	
E. Implementation and IT issues			
E1.	Do you prefer the new MCDA tool to be developed as an Excel workbook or a web portal?	Either would be acceptable. Slightly inclined towards Excel. DCCW want to use their EBSD model (developed by dLab) for WRMP24 as well. They expect to use the MCDA tool to help them elicit weights, scores, etc.	
E2.	Does your company IT policy allow running VBA Macro within Excel files?	Yes	
E3.	If we opt for a web portal, what IT issues might arise that we have to be aware of?	Upfront liaison with our BIS department would be required to ensure suitability with inhouse policies	

Table A.4: Interview responses from SSW

SSW	Question	Response	Action
A. MCDA tool/approach			
A1.	What were your MCDA tool/approaches for WRMP19?	MCDA	
A2.	What constraints did you include in your MCDA modelling? PCC, leakage, budget, etc? Where are you currently in terms of meeting the 50% leakage reduction target? Are you trying to meet it in regional level or water company level?	Budget at company level. Leakage at regional. We also optimised against environment and customer preference scores - these weren't delivery constraints, but different portfolios. We used the MCDA tool for PR19 investment programme too - so we also optimised on resilience	
A3.	What criteria do you currently use, and/or you think must be included in the model? Certain water companies will have challenges others do not have, can you elaborate on your challenges that should be reflected in a criteria and relevant metric? What criteria do you have that are inter-regional or inter-company?	We haven't used our MCDA model since PR19/WRMP19 - we consider the model to be obsolete now. Challenges we currently face with inter-regional tools - are that we are a part of two regional planning groups - which may lead to our company plans not being appraised in a consistent way	
A4.	For the above criteria, what unit you're using for the measurement? For example, leakage reduction can be expressed in Ml/d or l/p/d or l/Km.	Leakage is in Mld.	
A5.	What options (interventions/investment decisions) did you use for your WRMP19 decision-making?		
A6.	For WRMP19, how did you elicit values and priorities (e.g. weights and value functions) and who did you contact?	We carried out specific WRMP customer engagement whereby we gained a ranking for both supply and demand side options - this was then used in our MDCA tool	

SSW	Question	Response	Action
A7.	How did you quantify the performance of different plans? Did this come out of your EBSD model, if so how?	We used parallel axis plots to present the different portfolios	
A8.	How did you include supply-demand balance within in your MCDA tool (e.g. look up table, a simple Excel spreadsheet, etc.)?	It was a portfolio of constraints that could be pasted in from Excel	
A9.	How did you deal with uncertainty surrounding the performance of plans in your MCDA modelling? e.g. have you carried out a probabilistic sensitivity analysis, or scenario planning to deal with uncertainty?	We carried out multiple optimisation runs for sensitivity scenarios around growth, abstraction reduction and leakage reductions. Schemes that were selected in all portfolios became our no regret options	
A10.	How did you deal with uncertainty surrounding the values and priorities elicited from participants (if you've carried out this task in WRMP19)?	We didn't - these were ranked	
A11.	Do you already have in mind particular visual outputs and/or particular visual requirements for the MCDA ?	Parallel axis plots worked really to show the differences in each portfolio	
A12.	Following the assurance process for WRMP19, was there any particular recommendations from stakeholder groups/water companies that might be relevant to this project and we have to incorporate?	The translations of customer preferences into ranking - we did this internally and would recommend assurance on how this is carried out going forward	
B. EBSD modelling			
B1.	How did your carry out EBSD modelling for WRMP19?	we used out MCDA tool - an optimised on least cost	
B2.	What type of environment did you use for solving your EBSD problem? Was it developed	server sequl sql	

SSW	Question	Response	Action
	in Excel, in a mathematical modelling tool like AIMMS or GAMS or was it developed in Python (or another programming language)?		
B3.	Provide a brief description of your WRMP19 EBSD model inputs – outputs and their format.	Each option had a workbook which could be uploaded into the MCDA tool	
B4.	What physical/asset constraints did you use in your EBSD modelling?	We included options to maximise yield if they needed asset investment - i.e. treatment. We also included same sites with lower yield and no additional costs	
B5.	Do you rely on your current EBSD tool to determine scheduling of options or is it the MCDA tool that obtains this?	MCDA did this - we haven't re-run this analysis since WRMP19 as there have been no significant changes to supply/demand options that are available in period	
B6.	What are your current model runtimes?	MCDA, depending on the portfolio constraints were really long 8hrs plus - one of the reason we no longer use the tool	
B7.	How does your model handle supply deficit?	It wouldn't solve - the model had to hit the required/targeted SDB	
B8.	Did your model include metrics other than “least” cost (e.g. environmental benefit, resilience etc.)? If yes provide a brief list of the metrics with descriptions.	Yes - as above - env, cust, resilience	
B9.	Does your model support any type of multi-objective optimisation that allows exploration of portfolio of options that score good in different monetised and non-monetised performance metrics?	yes - the above aren't monetised in the MCDA	
C. Customer research/engagement			
C1.	What were the key customer engagement studies you relied on for WRMP19?	See next row.	
C2.	Please can you share the original reports from these studies?	All relevant research reports relating to WRMP were shared with Shed and FastTrack2 for WRW customer engagement group - if you don't have access to these let me know and we can send them over	

SSW	Question	Response	Action
C3.	How did you incorporate customer preferences in your WRMP19? Please be as detailed as possible; for example, did you formally incorporate measures such as willingness to pay, or priority scores, in an MCDA tool, or within your EBSD modelling? Did key decisions hinge on customer evidence? Or did you informally refer to customer evidence as a cross-check / validation of the outcomes of your WRMP process?	WTP included in MCDA tool. As detailed above, customer engagement preference results used for optimisation	
C4.	Can you share with us any document that are not on public domain, concerning how customers preferences were incorporated within WRMP19?	WRMP19 customer engagement appendix https://www.south-staffs-water.co.uk/media/2299/appendix-a07-pr19-data-triangulation-study-ssw-wrmp.pdf	
C5.	For WRMP24, WRW commissioned the FastTrack2 report 'Analysis of customer valuations for regional plan – WRW companies'. Is there a plan already in place concerning how this evidence is to be used?	Reports with Richard Blackwell from this study, not sure of next steps and how we are proposing to use these valuations.	
C6.	Are there any other plans in place regarding how customer evidence is to be used for WRMP24, or is it entirely up to us to develop recommendations in this regard?	We can share our WRMP24 research brief if it would help which provides a summary of how we are approaching customer engagement (please let me know if this is of use and I can send over). SSW is looking to form a working group with other water companies in WRW region to look at club projects for customer engagement and ensure alignment of key questions asked.	
D. Uncertainty/risks			
D1.	How do you take into account hydrological uncertainty in your decision-making process?	TBC	

SSW	Question	Response	Action
D2.	How do you include decision-making related (non-hydrological) uncertainties within the MCDA tool? A single best value plan might not be robust against unforeseen incidents.	TBC	
D3.	What risks (around security, budget, time, modelling approach, etc.) do you envisage for your decision-making process in this project?	Risk of alignment as Cambridge Water is in WRE and could end up with two tools - how to align between the two companies for consistency	
E. Implementation and IT issues			
E1.	Do you prefer the new MCDA tool to be developed as an Excel workbook or a web portal?	Excel	
E2.	Does your company IT policy allow running VBA Macro within Excel files?	If not, it could be resolved if excel is deemed the best option	
E3.	If we opt for a web portal, what IT issues might arise that we have to be aware of?		

B. Approach for the Strategic Environmental Assessment

B.1. SEA approach

For each feasible option, the SEA will assess the effects against each SEA objective for both construction and operation. This will be split by positive and negative effects (with effects either neutral, minor, moderate or major/significant), and will be presented in an assessment matrix as shown in Figure B.1.

Option	Stage	1. Biodiversity	2. Geology and Soils	3. Water Quantity and Quality	Etc...
Option Name	Construction (negative)	-	-	0	
	Construction (positive)	0	0	+	
	Operation (negative)	-/?	0	0	
	Operation (positive)	+	?	+++	

Construction

A description of the likely significant effects of the option under consideration on the SEA objectives during construction has been included here.

Operation

A description of the likely significant effects of the option under consideration on the SEA objectives during operation has been included here.

Figure B.1: SEA assessment matrix

Source: Ricardo, pers. comm.

The SEA assessment team has developed a method document that provides the qualitative and/or quantitative descriptions for each category of effect (i.e. how to allocate a +++ or a ---).

The SEA assessment results outputs will be spreadsheets containing the assessment matrix for each option proposed in each WRZ. To enable the symbol outputs of +++, --- etc. to be used easily within the MCDA process, a numerical value will be assigned to each category so that the results tables will be presented using the symbol outputs as well as the numerical outputs. The numerical values assigned to each symbol category are shown in Table B.1.

Table B.1: SEA symbol conversion table

SEA scoring symbol	Numerical value assigned to represent the symbol
+++	12
+++/?	11
++	10
++/?	9
+	8
+/?	7
0	6
-/?	5
-	4
--/?	3
--	2
---/?	1
---	0

Source: SEA scoring symbols from Ricardo, pers. comm.

The Natural Capital Assessment and Biodiversity Net Gain Assessment will also apply conversion tables to assign a simple numerical value to represent the symbols applied within the assessment process.

C. Proposal for the next phases of the project

C.1. Overview

This appendix sets out our updated proposal for the next phases of the project, based on discussion with WRW in relation to the Specification Note Release 01-00 and the modifications agreed to meet the requirements of the WRW team. The tasks and approaches for Phases 2 and 3 of the project are modified from our original proposal for the project.

The overriding requirement of WRW is to have a tool that can be delivered quickly and enable the water companies to use a simple and pragmatic approach for developing their draft plans to feed into the draft Regional Plan by August 2020. The tool needs to enable the generation of plans (with scheduling) as well as the selection of a best value plan.

Figure C.1 shows the proposed components of the decision tool (i.e. the inputs and outputs) and the pre- and post- process steps required for using the tool. The overall approach will be a weighted sum optimisation method for plan generation and selection. We explain these components and steps in Section C.2.

We propose to combine Phases 2 and 3 of the project so that Phase 2 becomes tool development and piloting and what was Phase 4 in our original proposal, to provide support to water companies for implementing the tool and generating their plans, is now Phase 3.

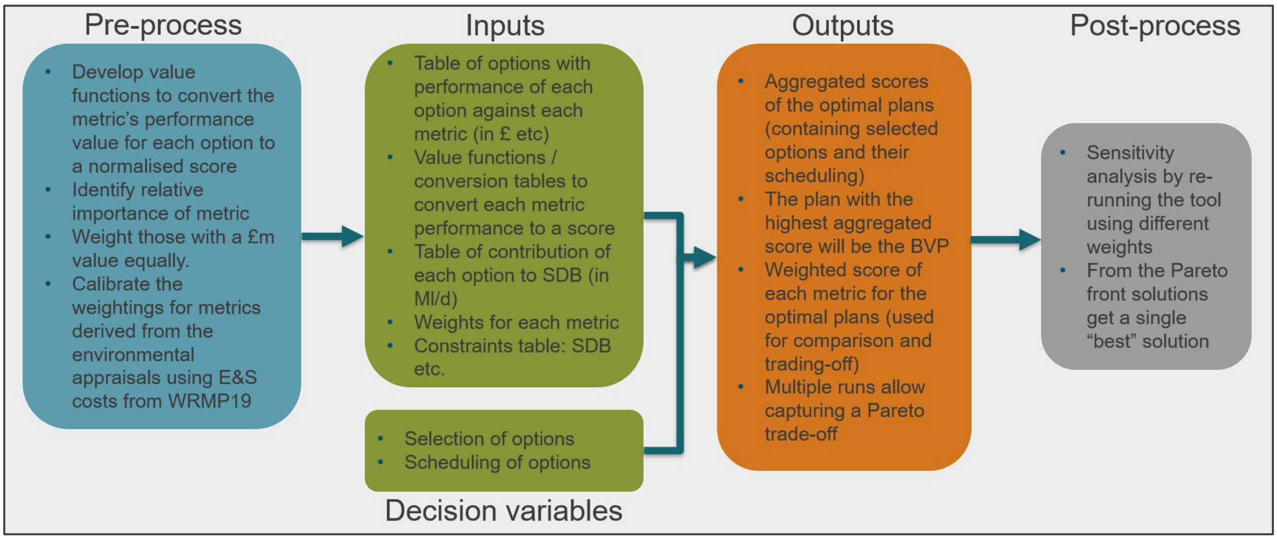

Figure C.1: Components of the decision tool (inputs and outputs) and pre- and post- process steps

C.2. Approach

C.2.1. Phase 2: Tool development and piloting

Task 2.1 Pre-process: develop metric scores and weights

As a pre-process for using the tool, it is necessary to develop scores and weights for the WRW decision metrics. This is similar to Step 4 in the BVP framework, but instead of scoring and weighting the metrics after the plan generation task in Step 3, it will be done before plans are generated in order to use the scores and weights in the weighted sum optimisation process for plan generation.

We will produce some hypothetical value functions to derive scores and hypothetical weights for the purposes of tool development and testing so that this pre-process step does not hold up the delivery of the tool. The hypothetical data will be determined rapidly, so as not to spend substantial effort on this given that detailed attention on scoring and weighting is provided in Task 2.2.

Task 2.2 Workshops on scoring and weighting

In parallel to the tool development, we will liaise with WRW to organise workshops for the WRW senior management team to elicit scores and weights through the collective decision making process. Once this workshop has taken place, the hypothetical value functions and weights in the tool will be replaced with those derived from the workshop, so that the results generated for the draft plan are based on the preferences and decisions of the WRW team (taking into account the preferences of stakeholders and customers).

Determining the overall value of options against multiple criteria requires that these performances be converted into a single scale. This is typically undertaken using scores and weights. Scores are used to convert different types of measurements into a scale from 0 to 100 and are used to determine how the different performances are valued, i.e. determine the relative value of changes within a criterion. Weights denote the relative value of changes on the different criteria, these are also referred to as trade-offs between criteria.

In assigning weights, the aim is to prioritise between the criteria; to evaluate if we are willing to accept some disadvantages of an option in order to get its benefits. For example, how much additional flood risk are we willing to trade in order to increase the social benefits?

To be able to elicit the scores and weights required as inputs to the decision tool, a number of steps will need to be carried out. This will involve a first workshop to determine the min and max performances of the SEA metrics at a plan level, and agree on the min and max for the other non-SEA metrics at a plan level. During a second workshop, the views of WRW on how to prioritise the different metrics will be gathered using a decision conference style elicitation. Two summary reports will be produced to document the process and the deliberations. An overview of the workshops is provided in Table C.1. We will discuss the format of the workshop, attendees, and expected outputs with WRW.

Table C.1: Overview of workshops

	Content	Duration	WRW Attendees	Consulting team
Workshop 1 – Performance ranges	Introduction	0.5 hour	WRW + SEA team	Paul Metcalfe Valerie Houlden
	Elicitation	3.5 hours		
Workshop 2 -Weight elicitation	Introduction	0.5 hour		
	Weight elicitation	3 hours		
	Weight scenario development for sensitivity analysis	0.5 hour		

For each workshop, we will provide a report summarising the outputs of the sessions which will document the work we have done to ensure transparency of our approach and the decisions reached by the group. This includes the structure and method to elicit preferences, performance metric data sources and assumptions behind the min and max, and the outputs of the preference elicitation exercise. We will summarise the reasoning that the workshop participants went through to provide their value judgements from the transcripts of the workshops. We will describe the consistency checks we have performed, the results obtained and implications of the workshop, and describe the study limitations.

Workshop 1: determining ranges of performance

It is important that trade-off judgements, also referred to as weights, are elicited over a realistic achievable range of performance. Given that we are eliciting these judgements prior to generating alternative plans, it will be necessary to obtain expert input for the expected realistic ranges of performance for each metric. These ranges need to account for uncertainty in these performances under pessimistic and optimistic scenarios, especially if these are later explored. These ranges will be determined over the course of a first workshop, described below.

A first workshop (summarised in Table C.1) will be held, facilitated by us, to determine:

- The min and max performances at the plan level on monetised metrics (Metrics 1, 2, 3 and 7). For these metrics, a linear scale will be assumed. This is a reasonable assumption in the case of this project given the relatively limited differences in performance ranges in relation to customers' bills.
- The values to assign to each SEA-based metric at the plan level, in proportion to their decision value. This will require experts from the environmental assessment contractors to attend, plus company representatives, with the aim of looking at how to combine sub-metrics at the option level, how to numerically score differences in levels, how to aggregate options within a plan, and the minimum and

maximum levels that should be considered for each metric, at the plan level, within the subsequent decision-making workshop.

The contribution of options towards the SEA metrics will likely be dependent on the scale at which they have impact, which could be reflected by the number of megalitres that the options contribute to per day. As a starting point for this stage of the work, we would assume that these can be aggregated via a weighted average based on the Ml/d contribution to the supply-demand balance, but we would seek to agree this, or an alternative approach at this first workshop. WRW may revise this processes post August 2021 for the next consultation.

It is assumed that an overall assessment of SEA will be used for all water companies within WRW and a single workshop will be required.

At the end of this workshop, the min and max performances will be summarised in Table C.2.

Table C.2: Metric ranges template

Ref.	Metric name	Unit (scale)	Min^	Max^
1	Cost	Economic valuation (£)		
2	PWS drought resilience	Economic valuation (£)		
3	Carbon costs	Economic valuation (£)		
4a	Flood risk – positive effects	Score or assessment		
4b	Flood risk – negative effects	Score or assessment		
5a	Human and social wellbeing – positive effects	Score or assessment		
5b	Human and social wellbeing – negative effects	Score or assessment		
6a	Sustainable natural resources – positive effects	Score or assessment		
6b	Sustainable natural resources – negative effects	Score or assessment		
7	PWS customer supply resilience	Economic valuation (£)		
8a	Multi-abstractor benefits – positive effects	Score or assessment		
8b	Multi-abstractor benefits – negative effects	Score or assessment		

Notes: Min^ and Max^ denote the range of outcomes between which the plans are expected to perform.

The Workshop 1 deliverables will be:

- Expected min and max performance for each metric; and,
- Workshop 1 summary report.

Workshop 2: determine weights

We recommend the **MCDA based elicitation technique MACBETH** (based on utility theory) during a **decision conferencing workshop** to elicit the trade-offs that workshop participants consider best reflect the relative importance of the criteria and the value of the plans against the criteria (summarised in Table C.2). The software Hiview3 will be used to support the elicitation process. Prior to the exercise, there will be an introduction to the task, the aim and the types of value judgements that will be elicited to ensure that the participants have understood the task.

Using the output of Workshop 1, the relevant data will be inputted into Hiview3 (in particular the list of metrics, and a set of hypothetical options to reflect the ranges of performances (min and max)) prior to the workshop as these will be required to enable expressing trade-offs. In addition, a presentation set of slides will be prepared to support the workshop session.

It is assumed that a single set of weights will be used for all water companies within WRW and a single workshop will be required.

To elicit the relative weights between the criteria, a method based on the swing weighting or MACBETH approach will be used. A workshop for WRW as a whole will be held, including the SEA team, to support the elicitation of the trade-offs between the criteria. The elicitation will also be supported via the software where the facilitator will be inputting the data elicited from the participants during the workshop discussions. It is anticipated that the workshop will last a maximum of 4 hours and will include an introductory session to ensure all participants understand the task as well as the weight scenario development for the sensitivity analysis (more details below).

When carrying out an MCDA, it is important to conduct sensitivity analysis to determine how disagreements between the different parties/stakeholders make a difference to the overall results. This is especially important for the appraisal of schemes/programmes that affect the public/customers and where there may not be consensus in the weights assigned.

Given that the subjective judgements elicited prior to deriving programmes are an input to the optimisation, an adapted version of the sensitivity analysis will be carried out, whereby a range of scenarios will be determined with respect to the profile of weights across the metrics. These will seek to reflect the range of views amongst companies regarding the relative importance of the metrics from the perspective of different groups. In particular, the scenarios will focus on varying the weights on the metrics which are already highly weighted, as these will have the biggest impacts on the solution. At least two scenarios will be created for such criteria, varying the weight by 5 and 10 (out of 100%) points in each direction[5].

It is important to note that the number of scenarios that can be practically run will depend on the runtime of the decision tool, which will be determined during the project when the runtimes are better known. The scenarios themselves will be agreed during the last part of the weight elicitation workshop.

Following this second workshop, a summary report will be drafted that will describe the process used, the decisions reached and the reasons behind these decisions. The rationale behind choosing the scenario weight profiles will also be determined.

The deliverables from Workshop 2 will be:

- Workshop 2 using Hiview3;
- Outputs of elicited weights;
- Scenario weight profiles for the sensitivity analysis;
- Workshop 2 summary report.

Task 2.3 Generate inputs

The decision tool will be developed in Excel. It will include worksheet tabs for the inputs, which are:

1. Table of options with performance of each option against each metric (in the units of the metric, e.g. £, SEA numerical value etc).
2. Table of contribution of each option to the SDB (in Ml/d).

[5] The weights on the other metrics will need to be renormalised as a result.

3. Constraints table setting out the constraints for the optimisation. This must include the SDB requirements.
4. Value functions or conversion tables to convert each metric performance to a score.
5. Weights for each objective and each metric.

We will create the format/template for these inputs within the Excel workbook (herein referred to as “the tool”) and liaise with WRW and the water companies to ensure that the format is appropriate. The tool will generate the effects table, using the value functions to convert the performance of metrics to a normalised score. The effects table will display the weighted score for each metric assessed for each option.

For the purposes of tool development and testing/piloting, we will propose to use data from one Water Resource Zone (WRZ), and will liaise with WRW and the relevant water company to obtain the data for Points 1-3 above for the pilot WRZ. If data is not available at the time of tool development (e.g. for SEA metrics), then hypothetical/”dummy” data can be used for the purposes of tool development.

The inputs for Points 4 and 5 will come from Task 2.1.

Task 2.4 Use the decision variables to implement the weighted sum optimisation

The tool will use an optimisation routine to generate plans and their scheduling. Plans and their scheduling will be optimally determined by maximising the weighted sum of scores for different metrics. As a result, the decision variables of the optimisation routine will be the selection of options and their scheduling. This optimisation routine will allow adding constraints. For instance, in addition to SDB-related constraints, some options are mutually exclusive, some options cannot be activated earlier than a fixed time, and some options might require ratchet constraints. Below, we describe the mathematical representation of the proposed weighted sum optimisation routine. Take O_1, O_2, … as options and T_1, T_2, … as their scheduling (hence forming the set of decision variables), with Z being the total score of a plan:

$$\max Z = W_1 M_1 \pm W_2 M_2 \pm \cdots$$

where W_1, W_2 and M_1, M_2, … are metrics’ weights and scores of a selected plan (P). Each plan consists of selected options and their scheduling ($P = \{(O_1, T_1), (O_2, T_2), \dots\}$). Use of ± will be dependent on the metric. For example, for a cost metric which has to be minimised, a - sign will be used. Metrics that must be maximised (such as human and social wellbeing) will enter the above equation with a + sign.

$$M_1 = \sum_i f(O_i) | t_i \geq T_i$$

$$M_2 = \sum_i g(O_i) | t_i \geq T_i$$

…

where f, g, … are value functions derived in Task 2.1 (following the workshop). The above equation indicates that the metric score will be calculated only for years of the planning horizon (t) after the scheduling time (T).

As the number of options input to the tool increases (normally such problems use a pool of hundreds of possible options), the chance of having multiple optimal (or near-optimal) solutions increases. In such cases, multiple runs of the tool will produce several candidate plans, each with a different combination of options and scheduling, and each of which represents an optimal plan in that the performance of any metric within each plan cannot be improved without decreasing the performance of another metric. If this is not the case and multiple runs lead to the same optimal solution, we consider that solution to be the BVP solution. Use of alternative approaches such as multi-objective evolutionary algorithms will allow capturing a trade-off for any given number of metrics in one go. A more sophisticated approach for optimisation is recommended when WRW programme constraints enable this possibility.

We will create a worksheet tab within the tool to implement the weighted sum optimisation. This will use the optimisation functionality within Excel and its built-in Simplex solver to optimise the selection of options and scheduling of options in order to generate candidate plans.

We will test the weighted sum optimisation process with the pilot WRZ data received for Task 2.2.

Task 2.5 Generate outputs

We will create a clear formatting of outputs within the tool. The outputs will be:

- The weighted scores for each metric for each of the candidate plans.
- The weighted sum of the metric scores for each candidate plan.

Task 2.6 Post-process: plan selection and sensitivity testing

1. Plan selection

We will create a post-process functionality within the tool to obtain a single best value plan from the Pareto optimal plans derived in Task 2.4. If no Pareto optimal solution was obtained in Task 2.4, this post-process stage must be skipped. The approach for plan selection will follow the work of McPhail *et al.* (2018)[6]. We will elaborate this using a simple example which uses the 'minimax regret' criterion. Note that minimax regret is one of the approaches represented by McPhail *et al.*, 2018. The minimax regret criterion seeks the smallest of the maximum regrets among the solutions. Assume we have a trade-off between two metrics M_1 and M_2. The 'regret' (R) for each of the Pareto trade-off points (j) can be calculated as:

$$R_j = \sqrt{\left(M_1^j - M_1^{opt}\right)^2 + \left(M_2^j - M_2^{opt}\right)^2}$$

where M_1^{opt} and M_2^{opt} are the optimum value for each of the metrics observed among the Pareto solutions (for a cost metric for example, this will be the solution with the lowest cost). After calculating all regret values for Pareto trade-off solutions, the one with the lowest regret can be considered the solution with the lowest loss when all metrics are considered. The minimax regret criterion is known to give a conservative yet optimistic decision. We propose to use the minimax regret approach for the plan selection of post-processing task.

2. Sensitivity testing

We will provide guidance on how the tool can be used to carry out sensitivity testing by re-running the tool with different value functions and weights. We will implement this for the pilot WRZ.

Task 2.7 Deliver the tool and provide guidance

We will deliver the complete tool to WRW and its water companies for use to generate and compare plans. This will be accompanied by a short guidance document to explain how to use the tool and what other activities can be done to support the development and selection of the best value plan.

This will include practical guidance on how to use the decision tool and approaches for programme appraisal. We will also include guidance on alternative customer engagement activities that could be

[6] McPhail, C., Maier, H.R., Kwakkel, J.H., Giuliani, M., Castelletti, A. and Westra, S. (2018), Robustness Metrics: How Are They Calculated, When Should They Be Used and Why Do They Give Different Results?. Earth's Future, 6: 169-191. https://doi.org/10.1002/2017EF000649

undertaken to supplement the evidence base on customer preferences. This will include guidance on the pros and cons of alternative stated preference methods, and on qualitative versus quantitative research, for companies to consider when planning and commissioning additional engagement.

C.2.2. Phase 3: Support

As per our original proposal, we can provide support to water companies throughout the development of WRMP24 and to WRW in developing its Regional Plan. We have retained the tasks in our original proposal but with less input given the change in scope for Phase 2, and included a more general support task for meetings with WRW and the water companies and ad-hoc advice on implementing the tool.

Task 3.1 Support on scoring and weighting metrics

This task allows some time for supporting water companies and WRW to evaluate whether the metric weights and value functions should be the same for the whole region or for each company/zone. This will require looking at the context of each company/zone within the region to evaluate if they potentially might have different priorities.

Task 3.2 Support on evaluation and comparison of alternative plans

Towards the end of the development of WRMP24 we can provide further advice on how alterative plans can be compared; sensitivity testing approaches and presenting the outputs of the decision process to support both company and regional plans. We will also provide support answering any questions from stakeholders and customers, including CCGs, Company Boards, EA and Ofwat.

Task 3.3 Support on tool implementation

This task is a general support task for meetings with WRW and the water companies and ad-hoc advice on implementing the tool. It is envisaged that beyond the tool delivery at the end of Phase 2, the water companies will use the tool to generate best value plans to collectively provide the components of the Regional Plan.

C.3. Programme

The proposed programme of work is shown below.

Week commencing	10-May-21	17-May-21	24-May-21	31-May-21	07-Jun-21	14-Jun-21	21-Jun-21	28-Jun-21	05-Jul-21	12-Jul-21	19-Jul-21	26-Jul-21	Beyond August
Phase 2 Tool development and piloting													
Task 2.1 Pre-process - develop metric scores and weights													
Produce hypothetical value functions and weights													
Task 2.2 Workshops													
Prepare and deliver workshops for eliciting value functions and weights													
Task 2.3 Generate inputs													
Get the data for the pilot WRZ													
Create template tables for inputs in the tool													
Task 2.4 Use the decision variables to implement the weighted sum optimisation													
Create the optimisation tool in Excel.													
Apply it on the pilot WRZ													
Integrate the EBSD generated plans													
Task 2.5 Generate outputs													
Format the outputs of the optimisation													
Task 2.6 Post process plan selection and sensitivity													
Provide plan selection functionality													
Do sensitivity testing on pilot WRZs													
Task 2.7 Deliver the tool and guidance													
Deliver tool - presentation to WRW, guidance on using tool													
Report preparation - guidance as set out in scope													
Phase 3: Support													
Task 3.1: Support on scoring and weighting metrics													
Task 3.2: Support on evaluation and comparison of alternative plans													
Task 3.3: Support on tool implementation													
Deliverables/client review													
Decision making tool Release 01-00	25/06/2021												
Guidance document Release 01-00	25/06/2021												
WRW team review period	02/07/2021												
Decision making tool Release 02-00	16/07/2021												
Guidance document Release 02-00	16/07/2021												

Figure C.2: Programme for Phases 2 and 3

C.4. Budget

The revised budget for Phases 2 and 3 of work is set out in Table C.3 and Table C.4.

Some notes of explanation on the revised costs compared with our original quote:

- Decision Lab is not able to be involved in Phases 2 and 3 of the project due to changes in staff. We propose to deliver the scope of Phases 2 and 3 with the HR Wallingford and PJM Economics team, with some small input from Catalyse to provide expert advice for preparing for and reporting on the workshops. Catalyse developed the Hiview3 software for eliciting value functions and weights.
- Phase 2 now includes tool development, covering both plan generation and plan comparison. In our original quote we assumed that plan generation was not part of the project scope and that bespoke tool development would not be required. Both of these requirements are now part of the Phase 2 scope.
- Phase 2 includes costs for delivering two workshops on eliciting metric scores and weights. The cost of preparing, delivering and reporting on these workshop is £10,884 (which is included in the Phase 2 figure of £43,353).

- Phase 2 includes the cost of purchasing one licence for Hiview3, which will be used to deliver the workshop. PJM Economics will purchase this for the purposes of the workshop and the licence and software can be transferred to one individual at WRW following the workshop.
- Phase 3 includes an additional task on support with implementing the decision tool.

Table C.3: Summary of fee breakdown by phases

Phase/cost	Staff hours	Staff cost	Programme management staff cost	Expenses	Total costs of phases
Phase 1: Scoping	90	£10,465		£0	**£10,465**
Phase 2: Tool development and piloting	379	£41,293	£330	£1,730	**£43,353**
Phase 3: Support	89	£8,166	£110	£0	**£8,276**
Programme management	8	£440	Included in Phases 2 and 3		
Licence Purchase fees (based on Hiview3)		£1,050		Included in Phase 2	
Report formatting		£680		Included in Phase 2	
TOTAL	566	**£62,094**			**£62,094**

Notes: See Table C.4 for full breakdown.

Table C.4: Fee breakdown

WRW decision tool and guidance

Supplier Name:	HR Wallingford and Hydro-Logic

(need breakdown by grade, and by hours/costs)	Hourly Rate (£)	Number of hours proposed per role	Total (£)
Hours			
Phase 1: Scoping			
Strategic Project Director (Paul Metcalfe and Sumitra Sri Bhashyam)		52	
Technical Director (Andy Ball and Mike Panzeri)		14	
Principal Consultant (Valerie Houlden)			
Senior Consultant (Majed Khadem, Rory Hodson, Alex Scarlat)		24	
Consultant (not used)			
Graduate Consultant (not used)			
TOTAL		90	**10465**
Phase 2: Tool development and piloting			
Strategic Project Director (Paul Metcalfe and Catalyse)		89	
Technical Director (Andy Ball and Mike Panzeri)		10	
Principal Consultant (Valerie Houlden)		130	
Senior Consultant (Majed Khadem, Rory Hodson, Alex Scarlat)		150	
Consultant (not used)			
Graduate Consultant (not used)			
TOTAL		379	**41293**
Phase 3: Support			
Strategic Project Director (Paul Metcalfe and Catalyse)		8	
Technical Director (Andy Ball and Mike Panzeri)		8	
Principal Consultant (Valerie Houlden)		25	
Senior Consultant (Majed Khadem, Rory Hodson, Alex Scarlat)		48	
Consultant (not used)			
Graduate Consultant (not used)			
TOTAL		89	**8166**
Programme management			
Strategic Project Director			
Technical Director			
Principal Consultant			
Senior Consultant (Alex Scarlat)		8	
Consultant			
Graduate Consultant			
TOTAL		8	**440**
Total Costs		**Total Hours**	**Total Cost**
Phase 1: Scoping		90	10465
Phase 2: Tool development and piloting		379	41293
Phase 3: Support		89	8166
Programme management		8	440
Licence Purchase fees (based on Hiview3)			**1050**
Report formatting			**680**
TOTAL		566	**62094**

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HR Wallingford is an independent engineering and environmental hydraulics organisation. We deliver practical solutions to the complex water-related challenges faced by our international clients. A dynamic research programme underpins all that we do and keeps us at the leading edge. Our unique mix of know-how, assets and facilities includes state of the art physical modelling laboratories, a full range of numerical modelling tools and, above all, enthusiastic people with world-renowned skills and expertise.

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