

Final report with DSS methodology, software and case study from an idealized pilot city

KOUROSH BEHZADIAN / MARK MORLEY / DIOGO VITORINO
SERGIO COELHO / RITA UGARELLI / ZORAN KAPELAN

trust

D54.3



Final report with DSS methodology, software and case study from a pilot city

Authors

Kourosh Behzadian (UNEXE)

Mark Morley (UNEXE)

Diogo Vitorino (ADDITION)

Sergio Coelho (LNEC)

Rita Ugarelli (SINTEF)

Zoran Kapelan (UNEXE)

Final Version for Distribution

April 2015

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 265122.

This publication reflects only the authors' views and the European Union is not liable for any use that may be made of the information contained therein.

TABLE OF CONTENTS

Table of Figures	3
List of Tables.....	6
Executive Summary	7
1. Introduction	8
2. Background.....	10
3. DSS Methodology	12
3.1. DSS Modelling concept.....	12
3.1.1. Decision Making Problem.....	12
3.1.2. DSS Structure	12
3.1.3. Principal Steps	14
3.2. Defining the DSS Problem	15
3.2.1. General Data.....	15
3.2.2. Scenarios.....	15
3.2.3. Performance Metrics	17
3.2.4. Intervention Strategies.....	17
3.3. Populating the DSS Decision Matrix	18
3.3.1. General.....	18
3.3.2. WaterMet ² model.....	19
3.3.3. Risk assessment model	21
3.4. Ranking Alternatives.....	22
3.4.1. Compromise Programming method.....	22
3.4.2. Analytical Hierarchy Process (AHP) method	23
4. DSS Software Tools	25
4.1. Desktop Tool	25
4.1.1. Getting started.....	25
4.1.2. Overview of data forms	27
4.1.3. Running the DSS.....	31
4.1.4. Retrieval of Results.....	34
4.2. Web-based Tool	35
4.2.1. Getting started.....	35
4.2.2. Overview of data forms	40

4.2.3.	Running the DSS.....	44
4.2.4.	Retrieval of results	47
5.	Case Study	49
5.1.	Problem description.....	50
5.1.1.	Scenarios.....	50
5.1.2.	Performance metrics	53
5.1.3.	Intervention Strategies.....	54
5.1.4.	Stakeholders preferences	55
5.2.	Desktop DSS Application.....	55
5.2.1.	Problem definition.....	56
5.2.2.	Population of Decision matrix.....	56
5.2.3.	Ranking of alternatives	63
5.3.	Web-based DSS Application.....	65
5.3.1.	Problem definition.....	65
5.3.2.	Population of Decision matrix.....	68
5.3.3.	Ranking of alternatives	69
6.	Summary and Conclusions	71
7.	References	73
8.	Appendices	76
8.1.	Appendix A: List of performance metrics supported by WaterMet ²	76
8.2.	Appendix B: WaterMet ² intervention options and associated variables.....	82
8.3.	Appendix C: Specifications of the intervention strategies specified in the numerical example	90

TABLE OF FIGURES

Figure 3.1 Principle mass fluxes modelled within the UWS metabolism by WaterMet ²	19
Figure 3.2 Required elements of the UWS analysed here including (a) main subsystems and components; (b) details of water demand profile and water recycling options	20
Figure 4.1 Opening the DSS	26
Figure 4.2 Error message if the DSS is not run with administrative privileges.....	26
Figure 4.3 Welcome form: in the start-up of the DSS software tool.....	27
Figure 4.4 General layout of the DSS.....	28
Figure 4.5 General data form	29
Figure 4.6 New Scenario form.....	29
Figure 4.7 New performance metric form.....	30
Figure 4.8 New intervention strategy form	31
Figure 4.9 New intervention option form	31
Figure 4.10 DSS Decision matrix.....	32
Figure 4.11 Form representing the running DSS.....	33
Figure 4.12 New weighting scheme.....	33
Figure 4.13 Overall ranking form in the DSS	34
Figure 4.14 Ranking form of a number of intervention strategies.....	35
Figure 4.15 First webpage of the TRUST DSS.....	36
Figure 4.16 Main form of web-based DSS.....	37
Figure 4.17 Tool list of the web-based DSS.....	38
Figure 4.18 Creating New file in web-based DSS.....	38
Figure 4.19 Openned existing file in web-based DSS.....	40
Figure 4.20 Edit scenario in web-based DSS.....	41

Figure 4.21 Edit scenario in web-based DSS	41
Figure 4.22 Adding scenario in web-based DSS	42
Figure 4.23 Editing alternative in web-based DSS.....	42
Figure 4.24 Editing metrics in web-based DSS.....	44
Figure 4.25 Web-based DSS ready for simulation	44
Figure 4.26 Simulation in progress for web-based DSS.....	45
Figure 4.27 Result page of the web-based DSS.....	45
Figure 4.28 Metrics over the different years of planning horizon.....	46
Figure 4.29 Exporting DSS matrix to MS Excel.....	46
Figure 4.30 Ranking of alternatives	47
Figure 4.31 Risk based representation.....	47
Figure 4.32 Different weighting in web-based DSS.....	48
Figure 5.1 Layout of the main components in the UWS for existing conditions.....	49
Figure 5.2 New scenario for the case study.....	57
Figure 5.3 Populated input data for both scenarios of the case study problem in the DSS....	57
Figure 5.4 An intervention strategy populated for the case study problem in the DSS.....	58
Figure 5.5 An individual intervention option populated for the case study problem in the DSS.....	59
Figure 5.6 List of populated intervention strategies for the case study problem in the DSS.	60
Figure 5.7 A performance metric (reliability) populated for the case study problem	61
Figure 5.8 Populated performance metric table for the case study problem	62
Figure 5.9 Quantified performance metrics for each intervention strategy in the case study problem	63
Figure 5.10 List of the three weighting schemes populated for the case study problem.....	64

Figure 5.11 Ranking table of intervention strategies including overall ranking obtained for all scenarios in the case study problem.....	65
Figure 5.12 Create a new DSS file	66
Figure 5.13 Frontpage of DSS new case.....	66
Figure 5.14 Form for selecting a WaterMet ² file	66
Figure 5.15 DSS form after opening a WaterMet ² file	67
Figure 5.16 Selecting metrics in web-based DSS	68
Figure 5.17 Population of decision matrices.....	69
Figure 5.18 ranking of alternatives.....	70

LIST OF TABLES

Table 1. DSS scenario types and associated variables.....	16
Table 2. Risk matrix for quantifying risk-based metrics.....	21
Table 3. Time series of annual factors for low rate of population growth and associated two water demands in the UWS	51
Table 4. Time series of annual factors for high rate of population growth and associated two water demands in the UWS	52
Table 5. Specifications of the performance metrics for the case study	54
Table 6. Metric weighting schemes according to differing stakeholder preferences.....	55

EXECUTIVE SUMMARY

The report presents a detailed description of a Decision Support System (DSS) methodology and software tool for use as a decision support tool to assist in the management of Urban Water Systems (UWS). The report is divided into the following three principal sections:

An initial description of the DSS methodology and modelling concept is followed by a definition of the DSS problem and the elements of the DSS decision matrix and, finally, the ranking of alternatives in the DSS. Specifically, this section describes the DSS structure which encapsulates a framework for the assessment of intervention strategies in an UWS. The internal structure of the DSS engine comprises three principle modules including Environment, Performance and Multi-Criteria Decision Analysis (MCDA). The 'Environment' module manages the specifications of the analysis including timing, intervention strategies, Pls, scenarios and customised model input. The 'Performance' module is responsible for evaluating the two categories of metrics: (1) quantitative performance metrics calculated by WaterMet² and the Risk Assessment module; (2) qualitative metrics defined within the DSS and quantified by external tools or third-parties outside the immediate scope of the DSS. The MCDA module applies a user-configured ranking approach to the specified intervention strategies for the purposes of scoring and ranking them for each scenario and user preference combination. The principal stages of the DSS map to four steps including 1) problem definition, 2) population of decision matrix and calculation of metrics (or impact assessment), 3) ranking of alternatives and viewing detailed results and 4) viewing result modification and re-evaluation of intervention strategies.

The second part describes the DSS software tool itself. Two complementary interface instances are presented for the DSS, representing Desktop and web-based tools. The overviews of both tools consist of an introduction to how input data are prepared, how to run a simulation and, finally, how to interpret results in different formats.

The final part of this report illustrates the use of DSS applied to the case study problem. This describes the configuration of the DSS for the case study problem for a city which faces water scarcity problems over a 30-year planning horizon, starting from year 2015. Seven intervention strategies for ameliorating this issue are examined through both implementations of the DSS. Six performance metrics are considered including five quantitative measures and a single qualitative criterion. The analysis accommodates two rates of future population growth (i.e. low and high) can be envisaged as two individual scenarios for a 30 year planning period starting from 2010. Comparison of the intervention strategies with respect to these performance metrics is also conducted based on three weighting schemes representing differing stakeholder perspectives. These weighting schemes include equal weights, and the perspectives of the Water Company and Consumers. The DSS is able to rank and prioritise the proposed intervention strategies under different individual specified scenarios and weighting schemes and to ultimately combine them to produce a single ranking for each intervention strategy.

1. INTRODUCTION

Urban Water Systems (UWS) face the long-term outlook of constraints and challenges associated with climate change, expansion of urbanisation, population growth and the limited availability of natural resources. This prospect requires the adaptation of the operation and infrastructure of UWS to meet uncertain future scenarios through the adoption of mitigating technologies. It is suggested the impact on the UWS of these technologies, prior to their practical implementation, is best evaluated by a Decision Support System (DSS).

This report presents a DSS which implements a tool which is able to quantify the impact of different combinations of interventions/technologies on the performance of the UWS, including associated risks and costs by evaluating a wide variety of sustainability performance metrics under different scenarios. The WaterMet² model (Behzadian *et al.*, 2013), which undertakes the simulation of the integrated modelling of UWS, underpins the computational output of this DSS.

This report is a TRUST project deliverable D54.3 (final report of WP54) as one of the outcomes of work done in WP54 and WP33. The report has been prepared based on the earlier recommendations made in deliverable D54.1, 'Integrated Decision Support Framework' Report (Morley *et al.*, 2012), deliverable D54.2, 'TRUST DSS Memo' report (Morley *et al.*, 2015), deliverable D33.1, 'WaterMet² conceptual model' report (Behzadian *et al.*, 2013), deliverable D33.2, 'quantitative UWS performance model' report (Behzadian *et al.*, 2014b) and the DSS integration memo (Vitorino *et al.*, 2014).

Two parallel, complementary versions of the DSS have been implemented, employing two different software systems and platforms (i.e. web-based and desktop tools), with feature sets that take advantage of those platforms' specific contexts and to target slightly diverse user groups. For example, in a situation where there is a necessity for data sharing and contributions from multiple stakeholders to achieve compromise solutions, the web-based environment is more easily accessed and is more efficient at sharing data to produce collaborative solutions. On the other hand, for experts who need to test a wider variety of alternatives in the preliminary phase, the additional functionality of the desktop version of the DSS for developing custom scenarios and alternatives is recommended.

The web-based tool is one of the modules available in Baseform's software deployment for the TRUST Project, alongside the AWARE-P IAM planning software portfolio — a non-intrusive, web-based, collaborative environment targeted at water utility professionals and decision makers. The system has been publicly available since 2012 and has gathered over 1200 registered users worldwide, having been used for IAM plan development in over 50 utilities in Europe, USA and Australia. The web-based tool shares the Baseform platform's visually-oriented interface and usage language, creating a degree of commonality with the available portfolio of tools, namely those developed under TRUST such as the PLAN comparison & decision tool, aimed specifically at managerial and technical roles in urban water services where decisions impact a number of stakeholders and interests.

The desktop DSS tool is designed to run under the Microsoft Windows™ operating system. It is a stand-alone software tool, however it is able to directly use the outputs of other deliverables in the TRUST project as inputs. More specifically, the WaterMet² model developed in WP33 can be used in DSS as a simulation model to support the assessment of intervention strategies in an UWS for the long-term planning of UWS. The desktop tool enables additional functionality over and above that available in the web-based tool. In particular, whereas the web-based tool requires that Intervention Strategies (Alternatives) be predefined in the WaterMet² input data, the desktop tool allows the end-user to interactively construct and evaluate their own Alternatives using any combination of the Interventions that are published by the WaterMet² model.

The report is organised as follows: (1) the first part outlines and describes the DSS methodology in which the key concepts of decision making, structure and principal steps used in the developed DSS are explained. This section also describes how to define a DSS problem, decision matrix and finally the ranking of various intervention strategies in the DSS. (2) The second part describes the DSS configuration in detail. This includes system requirements, an overview of the data entry requirements and the running and retrieval of results in both implementations of the DSS. (3) In the third part, the DSS functionality is demonstrated through the application to an idealized case study in the TRUST project through both user interfaces of the DSS outlined above.

2. BACKGROUND

Traditionally, the primary focus of water companies on the development of additional centralised infrastructure within the UWS has been for the purposes of contending with increasing water demand. However, this approach is hampered nowadays owing principally to limited water resources and other resources required for new infrastructure. On the other hand, with increased attention to sustainable development in recent decades, sustainable urban water management approaches have proved crucial to decision makers (Brown *et al.*, 2009). This implies that any development for providing water service requirements needs to pay attention to a variety of sustainability aspects including social and environmental impacts.

Hence, a wide range of urban water management options including water supply and water demand management are available for consideration in an UWS. Options can be applied to any components in water supply, wastewater and stormwater subsystems. In water supply and wastewater management, the options traditionally available include new/existing centralised infrastructure such as water resources, centralised water treatment and wastewater treatment works. Moreover, water demand management options can include both traditional and sustainable approaches. While traditional water management options include leakage control, water metering and charging with a view to decreasing water consumption, sustainable water management options suggest that centralised infrastructure is best combined with new/existing decentralised/semi-decentralised schemes such as rainwater harvesting and greywater recycling systems (Warner, 2006). Other independent sustainable options such as education campaigns for promoting lower water consumption along with smart appliances and fittings have also been shown to be efficient at the household, local area and system-wide scales (Butler and Memon, 2006).

Before these options can be practically implemented and incorporated into urban water systems, their performance needs to be simulated, analysed and evaluated alongside the other UWS components. Decision Support Systems have received attention from many practitioners and researchers in recent years, leading to the development of tools. A number of recently developed DSSs and software tools for this purpose are *AQUACYCLE* (Mitchell *et al.*, 2001), *UrbanCycle* (Hardy *et al.*, 2005), *UWOT* (Makropoulos *et al.*, 2008), *UVQ* (Mitchell and Diaper, 2010), *CWB* (Mackay and Last, 2010), *DUWSiM* (Willuweit and O'Sullivan, 2013) and *DMM* (Venkatesh *et al.*, 2014). These models typically employ a daily mass-balance based approach to simulate water related fluxes between UWS components in the context of the urban water cycle (e.g. clean water, stormwater and wastewater). The principal aim of these DSS tools is to assess the performance of centralised and decentralised water supply or water demand management options for the long term planning of urban water supply and water demand (Willuweit and O'Sullivan, 2013). Each of these DSS tools has strengths in their developments. Some DSS tools have focussed on water demand modelling at the household and neighbourhood scales, such as *UWOT* and *UrbanCycle* while some others have concentrated on modelling water and other fluxes at wider, system levels such as *DMM* and *DUWSiM*. Some of them have further considered the effects of urbanisation

scenarios and climate change on the urban water cycle as a whole (Willuweit and O'Sullivan, 2013).

Despite a plethora of systems relating to the integrated modelling of UWS being developed in recent years, there remain outstanding issues which need to be addressed in this framework (Bach *et al.*, 2014). Furthermore, none of the existing DSS implementations has considered a truly holistic approach in which the impacts on urban water services of an individual system component can be evaluated against the overall system performance and the external environment (Nair *et al.*, 2014). More specifically, there are three principal drawbacks in the developed models. First, most of the conceptual frameworks developed either consider the modelling between water demand point (starting with potable water from the point where it is delivered) and wastewater systems (Mackay and Last, 2010; Makropoulos *et al.*, 2008; Mitchell and Diaper, 2010; Mitchell *et al.*, 2001) or focus only on water supply systems between the water resource and water demand points (Rozos and Makropoulos, 2013). The second principal concern relates to the simultaneous coverage of the entire gamut of sustainability dimensions in the performance metrics, including both quantitative and risk-based metrics. Ideally, the PIs should reference all facets of sustainability including social, environment, economic, governance and assets (Alegre *et al.*, 2012). The existing models have focused mainly on the quantification of water flows while other sustainability fluxes such as indirect (embodied) energy fluxes and greenhouse gas (GHG) emissions across the full urban water cycle have been overlooked, or at least not considered in a systematic and holistic fashion (Mitchell and Diaper, 2010). Venkatesh *et al.* (2014) introduced a new decision support tool based on the concept of a dynamic metabolism model (DMM) with an annual time-base which can quantify various water and environmental fluxes in an integrated UWS framework. However, the DMM cannot transfer any simulated water flow between the separate system components and hence the environmental impacts are quantified by multiplying annual water production for each of the system components by a suitable conversion factor. Thirdly, most of the developed models follow a lumped approach for simulating water fluxes between different components at the system scale (Venkatesh *et al.*, 2014). Some models, which have assumed water flows within detailed spatial scales (e.g. cell and local area levels), balance water at the system (city) scale by aggregating all cell level processes of all cells in a particular area without considering the interconnections of different local areas (Mackay and Last, 2010; Makropoulos *et al.*, 2008; Willuweit and O'Sullivan, 2013).

3. DSS METHODOLOGY

This chapter presents the DSS methodology which has been used in the development of both implementations of the DSS (desktop and web-based tools). The methodology presented below is divided into three main sections as follows: The first section describes the modelling concept of the DSS; followed by the definition of a DSS problem in the second. Finally, the specification of the decision matrix in the DSS is detailed in the third section.

3.1. DSS Modelling concept

3.1.1. Decision Making Problem

For a long-term, strategic-level planning of Urban Water Systems at the city/system level, a number of alternative Intervention Strategies are usually proposed to contend with any possible limitations of the urban water service in the future. The selection of the most appropriate Intervention Strategy should be undertaken with respect to a number of different metrics and preferences expressed by stakeholders. Thus, a decision making framework is required for evaluating the proposed intervention strategies, comparing them and finally ranking and selecting the most appropriate with respect to the specified metrics and preferences. In addition, this selection can be subject to various external scenarios which can impact on the evaluation of intervention strategies. All this is handled through the DSS developed in this work package. The DSS seeks to support this process which is achieved through a novel methodology for the comparison and selection of alternative solutions, within the framework of long-term transition paths and amidst multiple decision criteria. Further details of the structure and principal steps of the DSS are described in the following sections.

3.1.2. DSS Structure

The assessment of intervention strategies in an UWS is encapsulated in a framework expressed through the DSS. The structure of the DSS back-end is divided into three principle modules: Environment, Performance and Multi-Criteria Decision Analysis (MCDA).

The ‘Environment’ module manages the specifications of the analysis including timing, intervention strategies, performance indicators (metrics), scenarios and any custom model input. The support offered by the DSS to the decision maker guides the user through the description of the “Environment” that the analysis takes place in, the generation and evaluation of intervention strategies and to rank and evaluate the results obtained. The user is also guided through the definition of the Environment configuration – i.e. the outline specification of the problem to be analysed. This assistance takes the form of:

- Defining a time horizon for the analysis, along with the intermediate times at which Interventions may be implemented.

- Defining Scenarios which comprise varying input parameters to the WaterMet² model or to custom metrics defined outside of WaterMet². Note that analysis of the UWS over some planning horizon in the DSS is the basis of a pre-specified scenario. Each scenario can influence a number of specific variables in WaterMet².
- Selecting the criteria to be used for evaluation from the list of available Metrics, along with defining any user preferences that are to be taken into consideration when ranking the proposed Intervention Strategies.

The user is then helped to generate one or more Intervention Strategies by specifying a set of interventions that are undertaken at the pre-determined times defined in the Environment Configuration. An Intervention Strategy is defined as one or more individual intervention options organized along the defined planning horizon. The DSS supports an existing library of individual intervention options which can be quantified by the WaterMet² model and which can be applied to many different components in the UWS.

The 'Performance' module undertakes the evaluation of the metrics which are split into two categories: (1) quantitative performance metrics calculated by the WaterMet² metabolism model and Risk Assessment modules; (2) qualitative metrics of the aforementioned types, defined within the DSS and quantified by external tools outside the immediate scope of the DSS. Through repeated execution of the WaterMet² model, each Intervention Strategy is evaluated to determine its effect on UWS performance. This is achieved by, firstly, applying each Scenario defined in the Environment Configuration in turn and also applying each Intervention in the Strategy in turn, at the appropriate time step. This process results in a series of metric values, for each time step and scenario, representing the performance of the system which are used to populate the decision matrices used by the ranking process. Further details of WaterMet² and Risk Assessment Modules are presented in sections 3.3.2 and 3.3.3.

Finally, the MCDA module applies a user-configured ranking approach to the specified intervention strategies for the purposes of scoring and ranking them for each scenario and user preference combination. Having created two or more Intervention Strategies, the principal role of the DSS is to undertake an automatic ranking of the Strategies using a MCDA technique. Two such techniques are implemented here, namely Compromise Programming (CP) and the Analytic Hierarchy Process (AHP). Further details of these two techniques are given in section 3.4. The ranking is performed according to the Metrics that have been identified in the Environment Configuration and is repeated for each combination of scenario and user preferences defined therein. Following ranking, the decision maker is supported in interactively modifying the intervention strategies and resubmitting it for the metric evaluation and rankings to be revised. Any number of Intervention Strategies can be created by the DSS and existing Strategies can be cloned and modified to assist in "what-if?" analysis, allowing variations of Strategies to be analysed in a straightforward fashion to investigate their influence on the overall rankings.

3.1.3. Principal Steps

In order to configure an evaluation of intervention strategies over a planning horizon in the DSS, the principal stages of the DSS are mapped onto four steps through 1) problem definition, 2) population of decision matrix and calculation of metrics (or impact assessment), 3) ranking of alternatives and viewing detailed results and 4) reconfiguration and re-evaluation of intervention strategies. The capabilities of the DSS developed are demonstrated on a real-life UWS in northern Europe. By way of the real case study, this report presents a walk-through for each stage, presenting a list of the scenarios, intervention strategies and metrics used. The values obtained after running the WaterMet² model and the risk module are shown, along with how those outputs are used in the population of the multi-criteria decision analysis decision matrix.

The first step (problem definition) comprises the specification of three principal components by the user:

1. Analysis Scenarios e.g. different population growth, climate change and other Scenarios which define the external conditions within which the UWS operates;
2. Performance Metrics of the UWS that will be used to assess performance of the system. Metrics may either be those exposed by the WaterMet² metabolism model or user-supplied.
3. Intervention Strategies (or Alternatives). An alternative comprises a set of individual interventions drawn from a predefined list of intervention options supported by the WaterMet² model. Each individual intervention is considered to occur at a specific time within the planning horizon and can have impacts on one or more constituent components of the UWS.

User-specified metrics and intervention strategies are also permitted. Scenarios and PIs quantified by WaterMet² can be specified by the user from the two separate lists available in the DSS while user-defined metrics should be quantified by the user using external tools feeding into the DSS. This step is further elaborated in section 3.2.

The second step in using the DSS involves: (a) running the WaterMet² simulation tool to populate the decision matrix with the relevant values, i.e. to calculate, for each scenario analysed, the impact of each intervention strategy (i.e. alternative) on each performance metric specified and (b) to manually entering any decision matrix values for each user-defined metrics. The metrics calculated by WaterMet² are automatically populated in the DSS, whilst others evaluated outside the DSS need to be entered manually by the user through the interface(s) provided.

Thirdly, the user is prompted to specify preferences (i.e. weights) for each metric, if desired. This allows the DSS to rank the intervention strategies by using a Multi Criteria Decision Analysis (MCDA) method according to alternative stakeholder perspectives. At this point the user can view the detailed results coming out of WaterMet² simulations, all for different alternatives, PIs and scenarios.

The final, fourth step, allows the user to add new or modify existing settings (including intervention strategies, metrics and/or scenarios) and to recalculate the rankings accordingly.

3.2. Defining the DSS Problem

A DSS problem can be defined through the following steps, described hereafter in more detail:

1. Specification of general data describing the problem analysed;
2. Specification of scenarios and associated data;
3. Specification of performance metrics and associated data;
4. Specification of intervention strategies and associated data.

3.2.1. General Data

The first stage of a DSS problem is to define the general data for the problem being analysed. Note that these data are not compulsory for the analysis but it is recommended as they provide some useful information for further analysis. The following data are required for this section.

- Name/description of the problem analysed;
- Planning horizon start year;
- Planning horizon time steps.

3.2.2. Scenarios

A scenario is used to define any anticipated external changes in the surrounding world (environment and/or society) over the analysed planning horizon. Scenario types and related information supported by the DSS are shown in Table 1. Four types of scenarios are supported including water demand growth, urbanisation, climate change and infrastructure ageing. Each scenario is defined in the DSS using the following information:

- Scenario ID
- Scenario description
- Scenario type
- Scenario likelihood
- List of variables associated with each scenario, each with relevant values defined over the planning horizon. Each variable has the following attributes:
 - Name
 - Units
 - Trend type (increase or decrease over planning horizon);
 - Variable type (single value, daily time series and annual time series)

Table 1. DSS scenario types and associated variables

SCENARIO TYPE	SCENARIO VARIABLES	UNITS	TREND TYPE	VARIABLE TYPE
Water demand growth	• annual population growth factor	-	increase	annual time series
	• annual industrial water demand growth factor	-	increase	annual time series
	• annual irrigation water demand growth factor	-	increase	annual time series
	• annual frost tapping water demand growth factor	-	increase	annual time series
Urbanisation	• total area of city	m ²	increase	single value
	• pervious area proportion	%	decrease	single value
	• pavement and road area proportion	%	decrease	single value
	• roof area proportion	%	increase	single value
	• runoff coefficient	-	decrease	single value
	• infiltration coefficient	-	decrease	single value
Climate change	• inflows into water resources	m ³ /day	Increase/decrease	daily time series
	• irrigation water demand	m ³ /day	increase	single value
Infrastructure ageing	• leakage rate in water supply conduits	%	increase	single value
	• leakage rate in trunk mains	%	increase	single value
	• leakage rate in distribution mains	%	increase	single value
	• capacity of water resources	m ³	decrease	single value
	• transmission capacity of water supply conduits	m ³ /day	decrease	single value
	• treatment capacity of WTWs	m ³ /day	decrease	single value
	• transmission capacity of trunk mains	m ³ /day	decrease	single value
	• capacity of service reservoir	m ³	decrease	single value
	• transmission capacity of distribution mains	m ³ /day	decrease	single value
	• transmission capacity of storm sewer	m ³ /day	decrease	single value
	• transmission capacity of combined /sanitary sewer	m ³ /day	decrease	single value
	• treatment capacity of WWTWs	m ³ /day	decrease	single value
	• infiltration rate of storm sewer	%	increase	single value
	• infiltration rate of combined /sanitary sewer	%	increase	single value
• exfiltration rate of storm sewer	%	increase	single value	
• exfiltration rate of combined /sanitary sewer	%	increase	single value	

3.2.3. Performance Metrics

The performance metrics are defined in the context of the TRUST framework of sustainability (Alegre *et al.*, 2012) spanning five dimensions: social, environment, economic, governance and assets. For the assessment of each of these objectives, the relevant criteria are specified and for quantitative or qualitative assessment of each criterion, performance metrics can be defined. The performance metrics supported by the WaterMet² model are quantitative performance measures of the UWS, listed in Appendix A. These performance metrics represents the basic list of metrics (i.e. usually expressed in the unit of days) which can be combined in some fashion by the user to derive further performance metrics or indices by using some simple statistics (e.g. spatial/temporal/subsystem level aggregation, averaging, etc.). For the assessment criteria which are not directly supported by WaterMet², the relevant performance metrics need to be quantified by other tools and specified by the user in the DSS.

Each performance metric in the DSS is defined as follows:

- Performance metric ID
- Performance metric description
- Performance metric data:
 - Performance metric type (e.g. water inflow, electricity, GHG emissions)
 - Performance metric units
 - UWS Component ID (0 representing total components)
- Performance metric quantification type (WaterMet² or user-specified)
- Performance metric goal type (optimisation or target):
 - If optimisation then either minimisation or maximisation
 - If target then:
 - Either single target value (valid over the planning horizon) or target profile (over the planning horizon)
 - Target type (to specify if above targets should be of the 'not above' or 'not below' or 'either' type).
- Performance metric normalisation values (min and max).

3.2.4. Intervention Strategies

An intervention strategy (or alternative) is defined as a set of individual interventions, each applied at pre-specified point in time over the planning horizon. A full list of individual intervention types which can be defined in the DSS (i.e. that are directly supported by the WaterMet² model) is provided in Appendix B. The following format is used for each intervention strategy in the DSS:

- Intervention strategy ID
- Intervention strategy description (name)
- A list of individual interventions each specified as follows:
 - Intervention description (name) (as in the above report)
 - Intervention timing:
 - Occurrence type (one-off or recurring)
 - First occurrence (time period on the planning horizon)
 - If recurring:
 - Frequency of occurrence (e.g. every year or every five years)
 - Time period (e.g. 25 years)
 - Intervention location in the UWS (ID of the UWS component e.g. WTWs/water supply and etc.)
 - List of variables associated with an individual intervention, each with relevant values defined over the planning horizon. Each variable has the following attributes:
 - Name
 - Units
 - UWS component ID
 - Magnitude
 - Variable type (daily time series, annual time series, single value or Boolean)

3.3. Populating the DSS Decision Matrix

3.3.1. General

For populating the DSS decision matrix, input data need to be specified initially, through the relevant DSS forms. By populating the scenarios, performance metrics and intervention strategies in the relevant forms, the 'Environment' part of the DSS is completed and the focus moves to the 'Performance' part of the DSS. Each intervention strategy needs to be evaluated over the planning horizon. This is effected by modifying the relevant WaterMet² input variables and parameters following the implementation of some intervention(s) and then rerunning the simulation from that point onwards, until the end of planning horizon is reached. Simulation of the UWS is carried out in the DSS using the built-in WaterMet² model.

As a result of running the DSS, the quantitative metrics are populated in the DSS decision matrix. Qualitative metrics need to be manually entered in the DSS decision matrix and these can be directly introduced into the decision matrix in both of the desktop and web-based implementations of the DSS through their respective interfaces.

3.3.2. WaterMet² model

As the built-in simulation model in the DSS, the WaterMet² model is used to calculate all non-risk performance metrics across an integrated UWS. This is handled through a simplified approach for modelling water supply, stormwater and wastewater systems based on mass-balance equations. WaterMet² is a conceptualized, simulation-type, mass-balance-based model which is used here to quantify metabolism related performance of the UWS over some long-term planning horizon (Behzadian *et al.*, 2014). WaterMet² tracks a number of metabolism based fluxes within the operating phase of the UWS by using a range of input mass fluxes (e.g. water inflow, precipitation, energy and chemical usage) as shown in Figure 3.1. This, in turn, enables WaterMet² to quantify the physical metabolism of UWS and therefore calculate performance metrics in the UWS including principal water-related flows (e.g. water demand, supply and contaminants into receiving water bodies), environmental-related fluxes (e.g. GHG emissions, acidification and eutrophication), financial flows and so on. Details of the principal flows and storage modelled in WaterMet² as well as descriptions of the components and their functionality can be found in Behzadian *et al.* (2013).

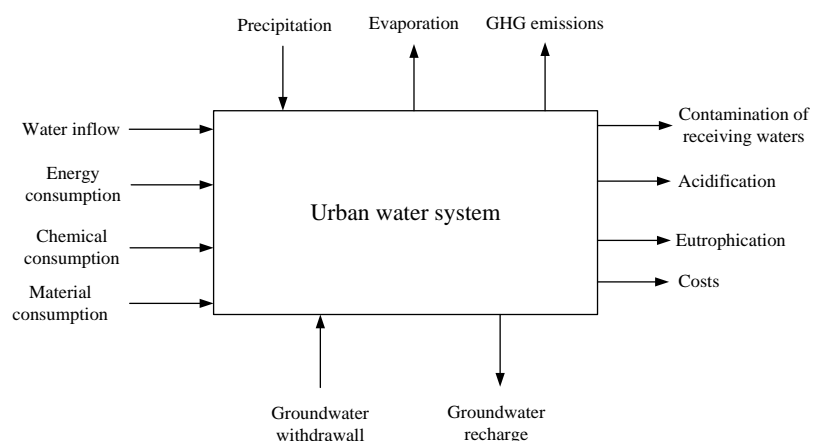


Figure 3.1 Principle mass fluxes modelled within the UWS metabolism by WaterMet²

The WaterMet² model is able to simulate the principal UWS components as shown in Figure 3.2. Any arbitrary number of each type of UWS components (e.g. conveyance type, storage type and subcatchment) can be defined in WaterMet². Moreover, WaterMet² can support various types of water demand profiles and water recycling options as seen in

Figure 3.2. This, in turn, enables WaterMet² to fully simulate rainwater harvesting and grey water recycling schemes in the UWS. WaterMet² can also support the simulation of treatment processes, chemical consumption, sludge and a number typical resource recovery options (e.g. biogas, ammonium nitrate and urea) in both WTWs and WWTWs. Further details of WaterMet² modelling processes and assumptions can be found in Behzadian *et al.* (2013) and Behzadian and Kapelan (2014b).

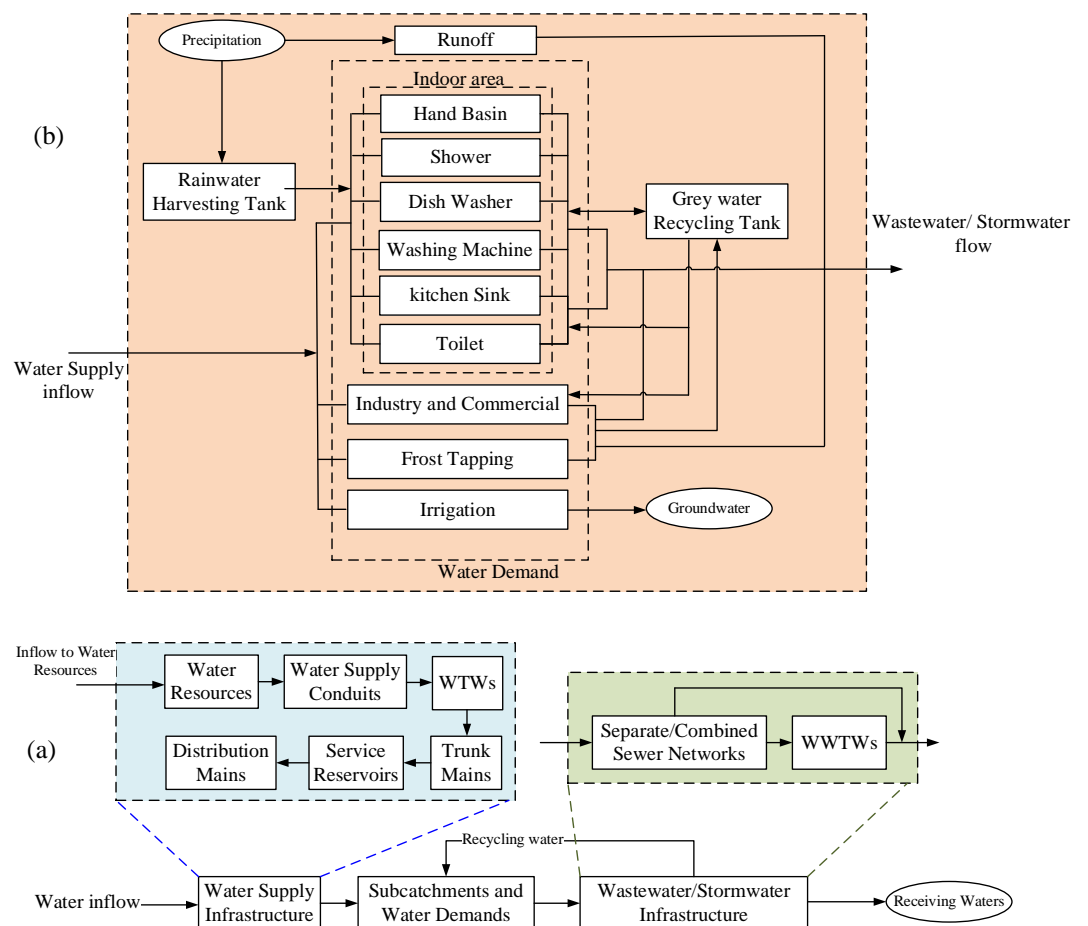


Figure 3.2 Required elements of the UWS analysed here including (a) main subsystems and components; (b) details of water demand profile and water recycling options

3.3.3. Risk assessment model

The risk assessment is based on the likelihood of occurrence and severity of consequences. The likelihood is assumed here as the probability of the scenario under analysis and is scaled in five levels, each associated with a specified probability range (Table 2). The likelihood scale needs to be as objective as possible. Therefore, it is recommended that a range of probability values should be defined for each class. Considering that consequences are established as deviations from the sustainability objectives, with corresponding criteria, metrics and targets, the consequence scale consists of levels defined by ranges of deviations from the set targets. A deviation can be expressed as a percentage or in any other way considered appropriate for each analysis. For each scenario, only some dimensions will be of interest, but the complete consequence scale needs to be defined prior to application. Scales used should be selected or constructed to reduce subjectivity in the application by different people as much as possible. The different dimensions of consequence have to be evaluated using comparable scales. A consequence in any class should have the same impact from the decision-maker's perspective, for all the dimensions considered in the application. Consequences are also defined as five levels (A-E) of deviations of absolute value of risk event from a specified sustainability target value (Table 2). The absolute value of the consequences is estimated based on the PIs obtained from the UWS simulation in the WaterMet² model. Note that the level of deviations for each metric needs to be converted to the summary scale as well (i.e. from A to E). Finally, the risk level can be estimated based on the assessment of likelihood and consequence levels for each event using a selected risk matrix, as shown Table 2.

Table 2. Risk matrix for quantifying risk-based metrics.

		Probability Range	Consequence level				
			E	D	C	B	A
Likelihood level	5 <i>Almost certain</i>	$P > 10\%$	5E - Med.	5D - Med.	5C - High	5B - High	5A - High
	4 <i>Likely</i>	$2\% < P \leq 10\%$	4E - Low	4D - Med.	4C - Med.	4B - High	4A - High
	3 <i>Moderate</i>	$1\% < P \leq 2\%$	3E - Low	3D - Med.	3C - Med.	3B - Med.	3A - High
	2 <i>Unlikely</i>	$0.2\% < P \leq 1\%$	2E - Low	2D - Low	2C - Med.	2B - Med.	2A - Med.
	1 <i>Rare</i>	$P \leq 0.2\%$	1E - Low	1D - Low	1C - Low	1B - Low	1A - Low

3.4. Ranking Alternatives

Intervention strategies built using the DSS can be compared and ranked with respect to a number of different metrics. Two well-known MCDA methods are implemented in the DSS for the purpose of ranking intervention strategies under different scenarios and user preferences: the Compromise Programming (CP) method (Zeleny, 1973) and the Analytical Hierarchy Process (AHP) method (Saaty, 1980). The two methods were selected because of their widespread use but also because they use different ranking technologies and, also, allow users to express their preferences in different fashions. In the CP method, user preferences are specified as criteria weights making this method more suitable for use by less experienced users. In the AHP method, user preferences are specified via the pairwise criteria-importance comparisons. Both CP and AHP methods can be used for group decision making and for identifying preferences of each metric. The selection between the two methods is largely dependent on the decision maker's preferences and experience. Some users may find that nominating a preference for each pairwise comparison in AHP is simpler and easier than giving a numeric weight in the CP method. However, if AHP is employed, the calculated inconsistency ratio (Saaty, 1980) should be less than 10% to ensure the pairwise comparisons are consistently balanced. In addition, for numbers of criteria above 9, it may be difficult to achieve the required consistency (Saaty, 1980). Moreover, specifying the pairwise comparisons for large numbers of metrics can be a time consuming task. On the other hand, the final ranking in the CP method can be somewhat sensitive to extreme (absolute) values of ideal and non-ideal points of the individual metrics, which may need further attention from decision makers. The DSS enables the user to select the method to use when solving a particular problem, including the possibility to use both methods on the same problem and then to compare results (e.g. to see if there an alternative solution that is ranked consistently highly irrespective of the MCDA method used). Note that sensitivity analysis cannot be conducted automatically in either version of the DSS. However, it is possible to emulate this facility through varying the parameters of interest in the metabolism-based WaterMet² simulation model and to recalculate the metrics and consequent rankings in the DSS.

3.4.1. Compromise Programming method

The CP method originally proposed by Zeleny (1973) calculates a distance function for each strategy based on a subset of efficient solutions (called the compromise set) that is “nearest” to an ‘ideal’ point, for which all criteria are optimized (André and Romero, 2008). The strategies are then ranked according to these distances. Without loss of generality, assuming all criteria are maximising, the overall distance function for an intervention strategy with an evaluation function (f_j), maximum (f_j^*) and minimum (f_{j*}) absolute values, and weight or relative importance (w_j) for each criterion and a topological metric of p is calculated as

$$\text{minimise } L_p \equiv \left[\sum_{i=1}^{n_{\text{criteria}}} \left(w_i (f_i^* - f_i) / (f_i^* - f_{i*}) \right)^p \right]^{1/p}, \quad w_i > 0, 1 \leq p \leq \infty \quad (1)$$

3.4.2. Analytical Hierarchy Process (AHP) method

The AHP method initially proposed by Saaty (1980) is a structured technique for organizing and analysing complex decisions which has been widely used for multi-criteria decision making. The AHP method requires decision makers to explicitly state the exact value of their opinion in a pairwise comparison. Generally, AHP allows the user to specify two levels of pairwise comparisons: (1) pairwise comparison of alternatives (intervention strategies) with respect to each criterion; (2) pairwise comparison of criteria with respect for specifying the priority of criteria relative to each other. Here only the second level of pairwise comparisons are used as the WaterMet² model and other tools can quantify the performance of each intervention strategy with respect to assessment criteria. Hence, assuming the matrix of pairwise comparisons (A) of all criteria (a_{ij}) are expressed in Eq. (2), the relative weight (priority) of each criterion (W_i) is calculated in Eq. (3) as

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \quad (2)$$

$$W_i = \begin{bmatrix} \frac{1}{n} \sum_{j=1}^n a_{1j} / w_j \\ \vdots \\ \frac{1}{n} \sum_{j=1}^n a_{nj} / w_j \end{bmatrix} \quad (3)$$

Where: $w_j = \sum_{i=1}^n a_{ij}$ and n= number of criteria. Finally, the total weight of each intervention strategy (F_j) can be calculated according to Eq. (4) where f_{ij} is the normalised performance of strategy j relative to other strategies for criterion i . As a result, F_j represents the final score of each strategy and therefore the strategy with the highest score is the best and thus the others are ranked likewise in descending order.

$$F_j = \sum_{i=1}^n W_i \times f_{ij} \quad (4)$$

3.5. Risk-based prioritization

Deliverable D32.1 (also Section 3.3.3 above) presents the methodology for assessing the risk associated with an urban water system not reaching sustainability. The methodology essentially follows the standard steps of a risk management process. These assuming that established sustainability objectives are defined for a specific system, risks can be identified in the context of occurrence of circumstances as events causing undesired and uncertain deviations from the objectives (risk defined as effect of uncertainty on objectives in ISO 31000 (ISO, 2009). In each specific application, the sustainability objectives need to be

expressed by an appropriate set of criteria, supported by appropriate metrics and corresponding targets. The deviations from the expected situation in relation to the set targets, resulting from the occurrence of the undesired circumstances, are the corresponding consequences.

An extension of the risk methodology described in Deliverable D32.1, is applied in the DSS using risk to rank scenarios. A prerequisite to its application is the selection of a likelihood of each given scenario and that the distance from a set sustainability objective, computed for each alternative under each scenario, is defined as the consequence: the higher the distance, the higher the (negative) consequence.

The DSS uses the WaterMet² metabolism model to calculate a number of performance metrics/indicators which represent the effect of choosing any particular alternative on different sustainability dimensions through time. Thus, from a city-level sustainability standpoint, the consequence of choosing any particular alternative can be effectively measured by running a WaterMet² simulation and assessing performance metrics and their deviation from predefined goals.

The Compromise Programming MCDA method analyzes the selected performance metrics for each of the different alternatives and weighting strategies and is able to rank them by determining a distance value for each alternative which represents how much far alternative strategy diverges from ideal goals, aggregating time and metrics. These distance values and corresponding alternative rankings are calculated for each defined scenario.

A risk based, city-level sustainability approach allows for prioritizing the alternatives across scenarios. As for the assumptions in D32.1, each scenario, as for the described extension, can be seen as a risk event with determined probability and consequence, where probability is given by analyzing the likelihood of each particular scenario and the consequence can be assessed as deviations from metric defined sustainability goals, as measured by the Compromise Programming distance calculation.

4. DSS SOFTWARE TOOLS

4.1. Desktop Tool

4.1.1. Getting started

Before installing the software, the user needs to check the system requirements to ensure that it is fully compatible with those of the software. After successful installation, the user can start working on either a new model or existing model. The full package of the software tool is freely available for users and can be accessed either on request from the developers or for downloading from the TRUST website (<https://www.trust-i.net/>).

The system requirements for installing the software are as follows:

- Operating System: Windows 8, Windows Server 2012, Windows 7, Windows Vista SP1 or later, Windows XP SP3, Windows XP SP2 x64 Edition, Windows Server 2008 (Server Core not supported), Windows Server 2008 R2 (Server Core supported with SP1 or later), Windows Server 2003 SP2. Windows RT is not supported.
- The DSS uses Windows™ based screens, and navigational devices such as buttons, drop-down menus and toolbars. The Minimum Screen Resolution is 1152x864 but a resolution of 1680x1050 or higher is highly recommended.
- Windows Regional Settings: any language is allowed when installing the software. However, for using the examples in the case study section, it is recommended to configure Windows to use “.” as the decimal point symbol,

The DSS software model is designed to run under a Windows™ operating system. It is distributed in as a compressed folder which includes a WP54DSS.EXE file which runs the program on Windows. The contents of the compressed folder should be extracted to the same directory. The WP54DSS.EXE file is an executable file but in order to run this executable file, the user needs to right-click on this file and select “Run as Administrator” (Figure 4.1). This step is necessary as the software opens an internal web-server which is used to communicate between the front-end of the software and the back-end (including WaterMet²) which is common to both the web and desktop versions of the DSS. On successful start-up, the initial appearance of the DSS software tool is shown in Figure 4.3. Note that some dependent DLL files in the distributed folder must be kept in the same folder as the executable when running the DSS tool. Note that if any of these files are missing, the DSS will not be able to start.

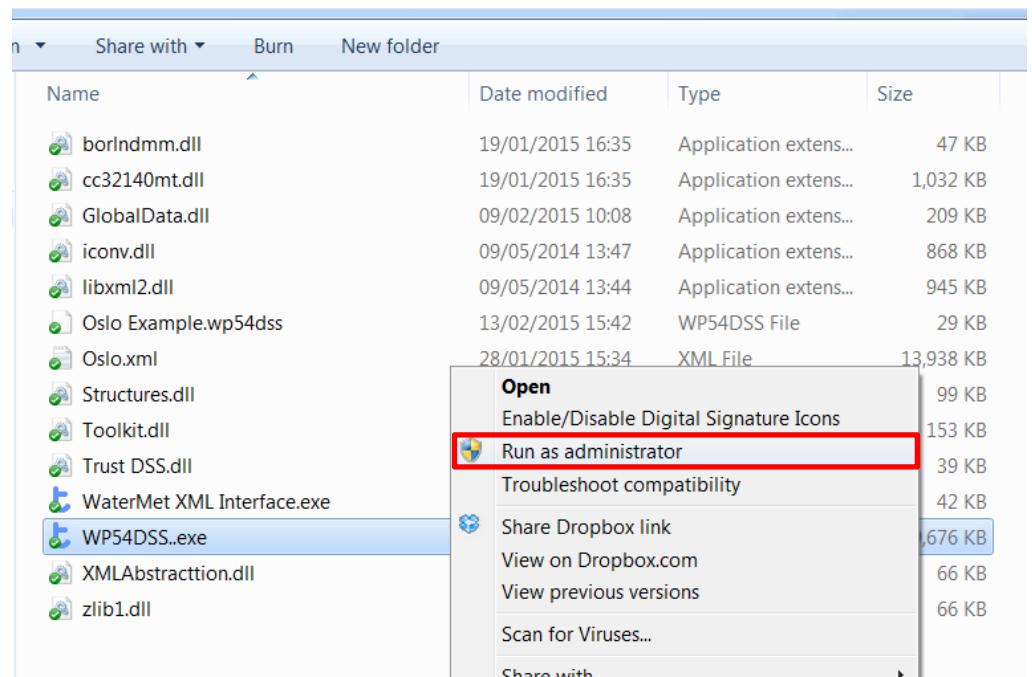


Figure 4.1 Opening the DSS

If the user, instead of right-clicking on the executable file (WP54DSS.EXE) and selecting “Run as Administrator”, left-clicks on the executable file, the error message shown in Figure 4.2 will appear and the DSS will be unable to function correctly. In the event of this error message appearing, the user should close the DSS and open it again with administrative privileges, as shown above.

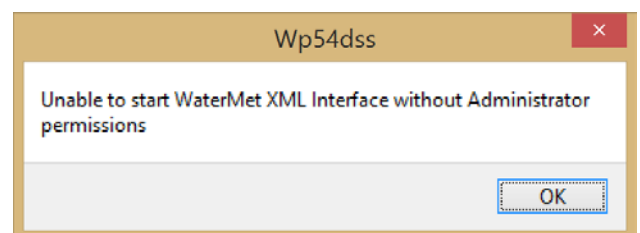


Figure 4.2 Error message if the DSS is not run with administrative privileges

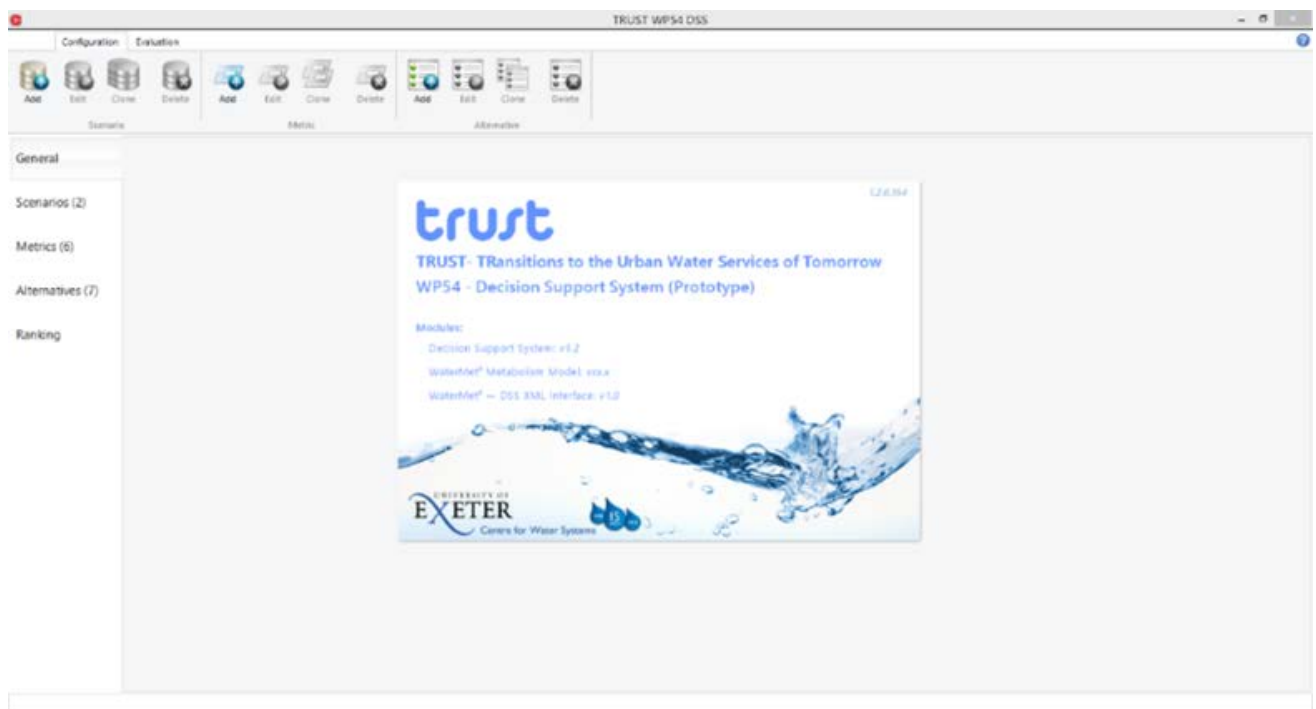


Figure 4.3 Welcome form: in the start-up of the DSS software tool

4.1.2. Overview of data forms

The main input data of the DSS are categorised in three main sections: Scenarios, Metrics and Alternatives. These input data need to be specified and populated by selecting the buttons in the configuration menu on the left-hand pane of the DSS window, as shown in Figure 4.4

For each of the three parts of these data, there are four buttons available in the top ribbon menu for the user to **Add**, **Edit**, **Clone** and **Delete** the associated entries. These buttons are explained below in further details when describing each class of input data for the case study problem.

There are two ways of opening a DSS file as follows: (1) opening an existing WaterMet² model file as .xml using a big button (**Open WaterMet² Model ...**) in the centre of the DSS form. This loads all of the available metrics, scenarios and potential interventions supported by WaterMet² into the DSS (Figure 4.4). Note that when building a new DSS project from scratch, this method of opening needs to be used. (2) Opening an existing DSS file (which has the file extension .wp54dss) using a big button (**Open Project ...**) in the centre of the DSS form (Figure 4.4). This allows the loading of a previously saved DSS file in which all three main DSS input data (i.e. Scenario, Metrics and Alternatives) will already be specified.

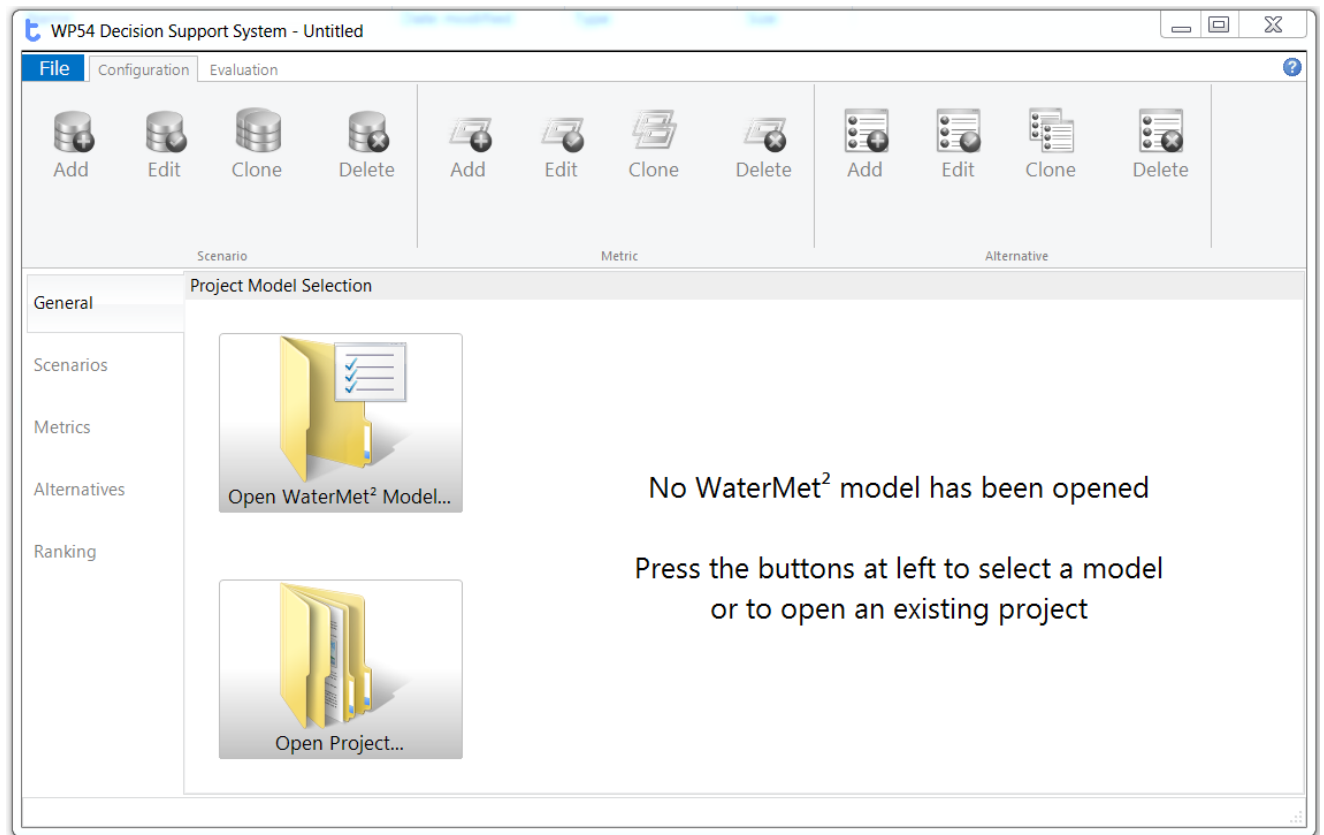


Figure 4.4 General layout of the DSS

Specification of general data describing the problem analysed can be populated at first as shown in Figure 4.5. Note that populating all these text boxes are not necessary for implementing for running the DSS. Counts of the loaded scenario, metric and intervention types are presented on this form, also.

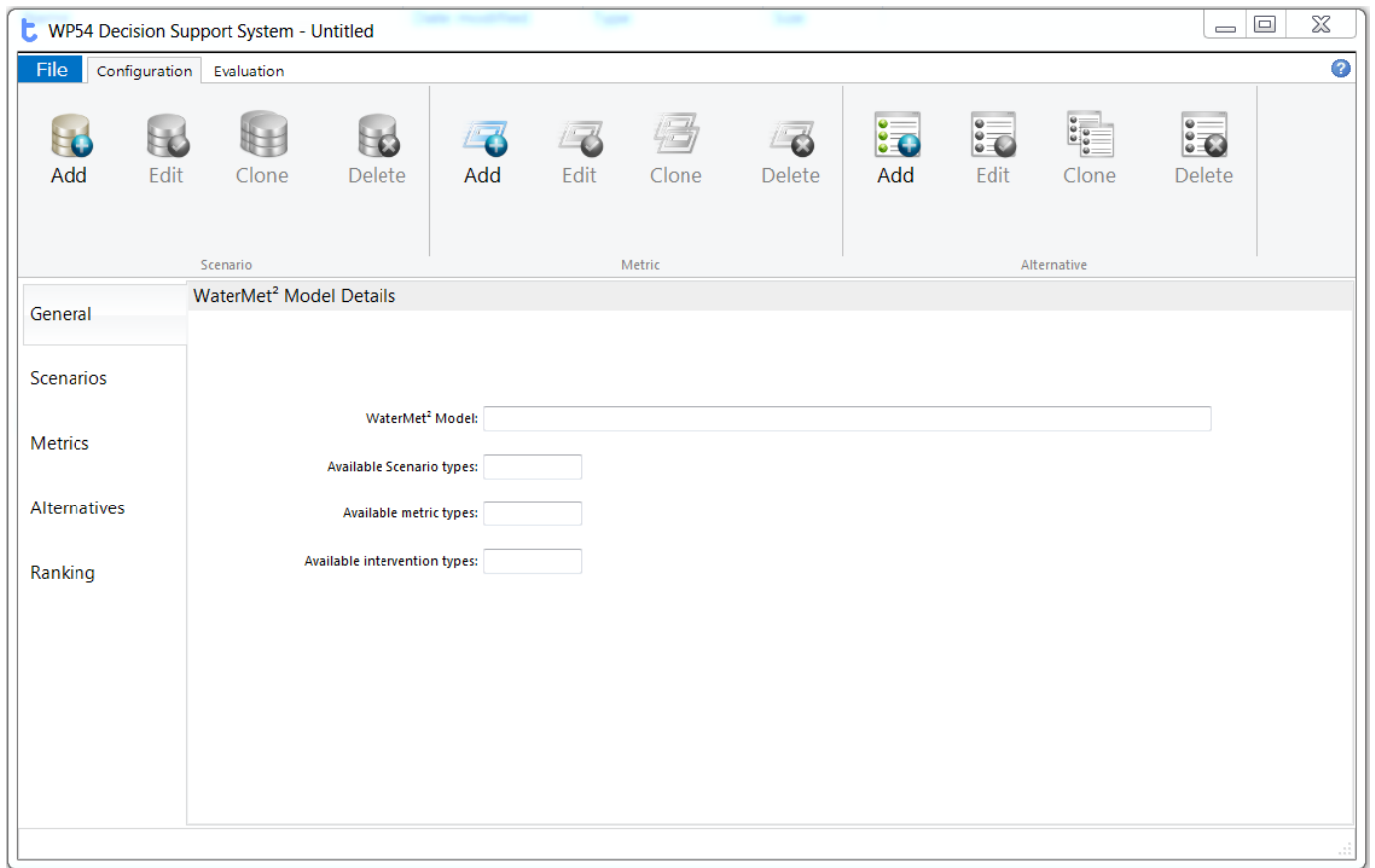


Figure 4.5 General data form

A new scenario in the DSS can be added using the form shown in Figure 4.6 . The user needs to specify a User ID, description and type of scenario in this form type. The user can define several scenarios for analysis in a single run of the DSS.

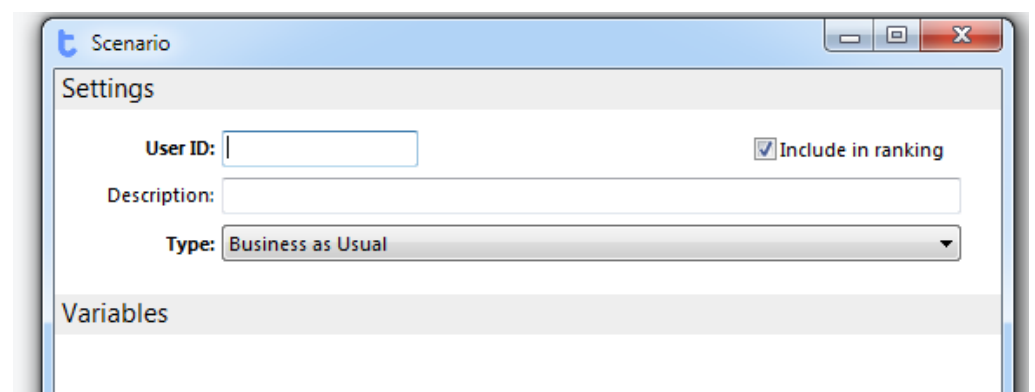


Figure 4.6 New Scenario form

A new performance metric form is shown in Figure 4.7. This form allows the user to firstly specify a new metric, assigning it a User-specified ID and description. The new metric can either be one supported by WaterMet², in which case the metric to be used should be selected from the drop down list, or a user-defined metric which will require manual population in the decision matrix. In addition, further information required for each metric includes the optimization type to be applied to each metric (i.e. none, minimize, maximize, target, 'at least', 'at most') and processing (aggregation, resampling and consolidation).

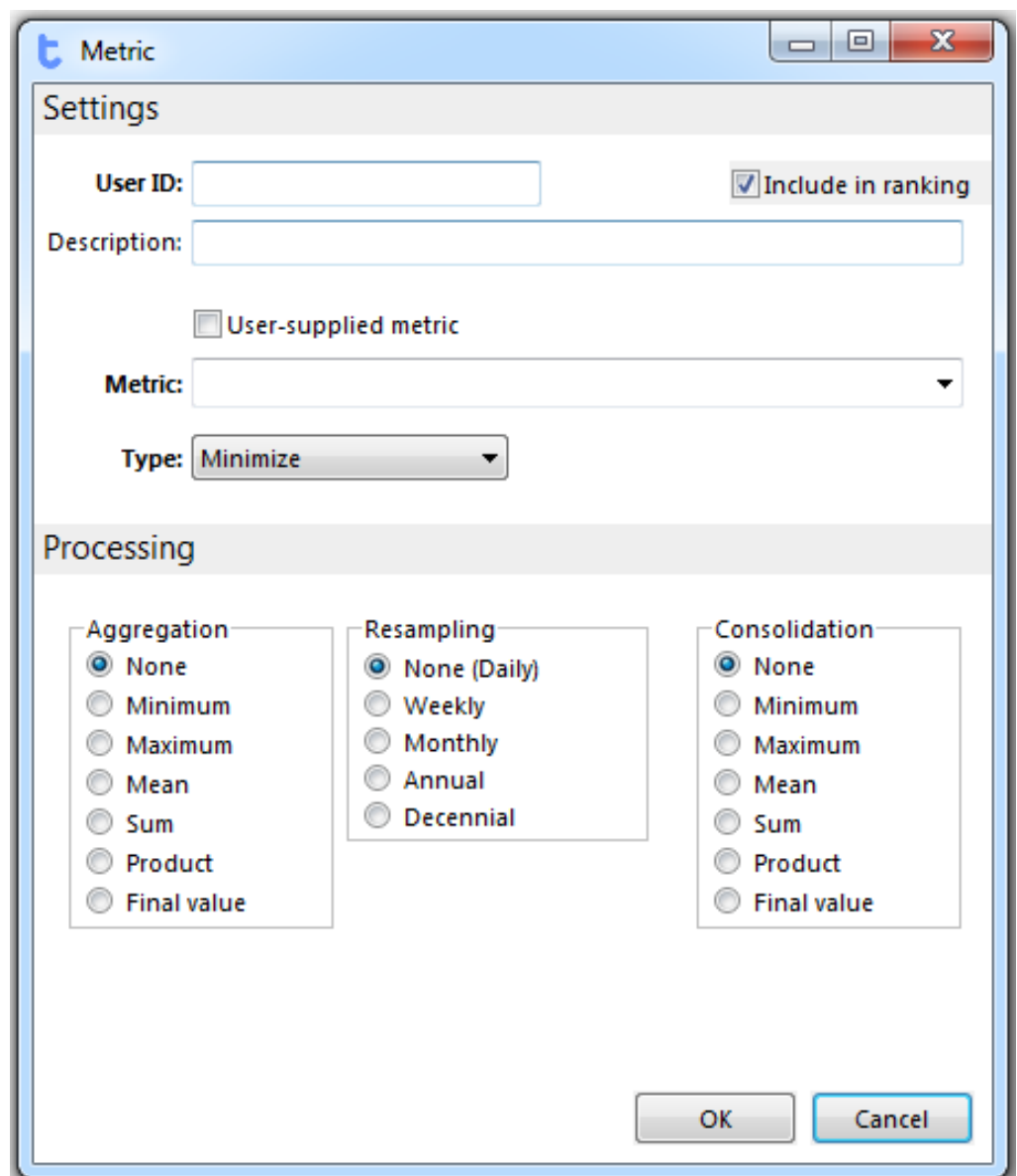


Figure 4.7 New performance metric form

A new alternative (intervention strategy) can be added by clicking **Add** button in **Alternative** section of the **Configuration** ribbon menu (forms shown in Figure 4.8 and Figure 4.9). For a given alternative, a new individual intervention option can be added by clicking **Add** button

in the Alternative form. This pops-up a dialog permitting the user to specify the characteristics of an individual intervention option supported by WaterMet² (Figure 4.9). For each newly added intervention option, a specific time on which the intervention will be implemented in the UWS is also specified. When a WaterMet² intervention type has been selected, any associated variables are displayed in the lower portion of the form and the values of those variables can be modified directly, as appropriate.

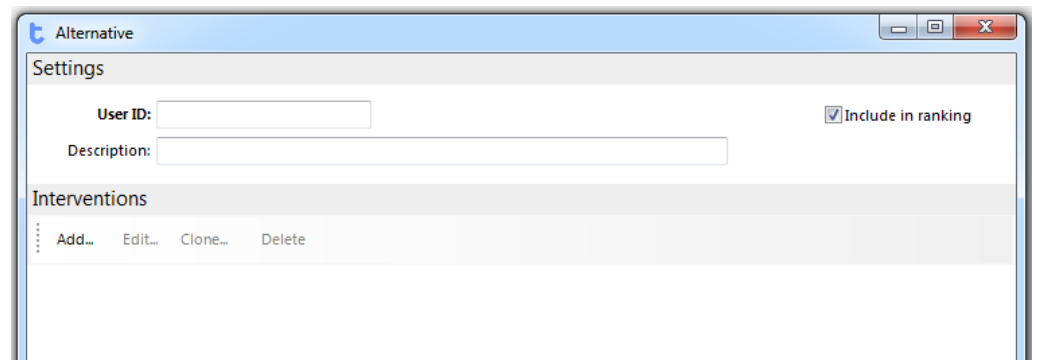


Figure 4.8 New intervention strategy form

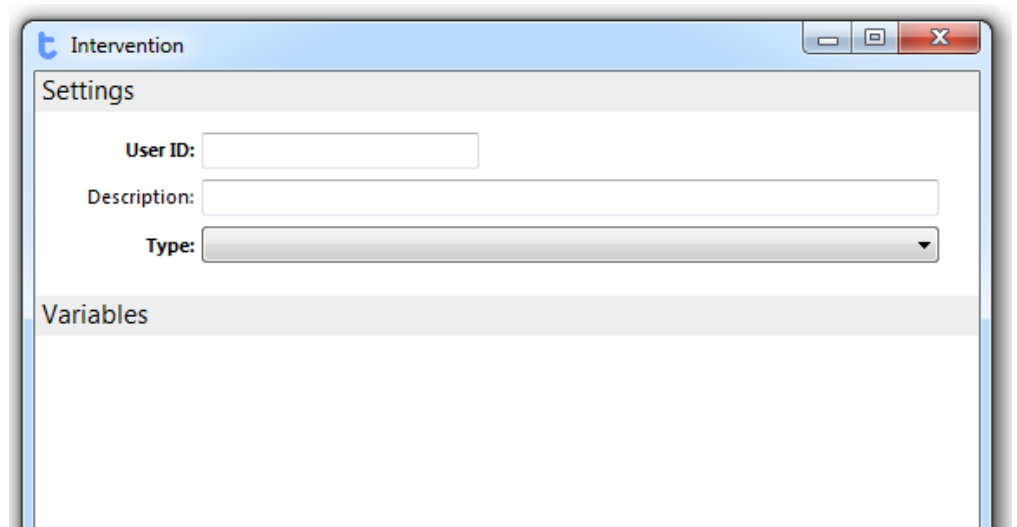


Figure 4.9 New intervention option form

4.1.3. Running the DSS

After populating all three main elements of input data, the DSS can be run through the evaluation ribbon which consists of two main tabs: (1) Ranking and (2) Weighting as shown in Figure 4.10 . Firstly, the DSS decision matrix needs to be populated with values calculated by the WaterMet² metabolism model. These quantitative metrics can be populated by clicking the “Populate Matrix” button in the ribbon. This procedure may take

some time as each intervention strategy needs to be simulated for each of the different scenarios that have been defined. The progress of the DSS running is shown during the calculation process (Figure 4.11). On completion, the numeric values for each of the metrics populated in the decision matrix table. Any qualitative metrics associated with the analysis should also be populated at this point by the user using other tools outside the DSS. The relevant metric values can be manually populated directly in the decision matrix.

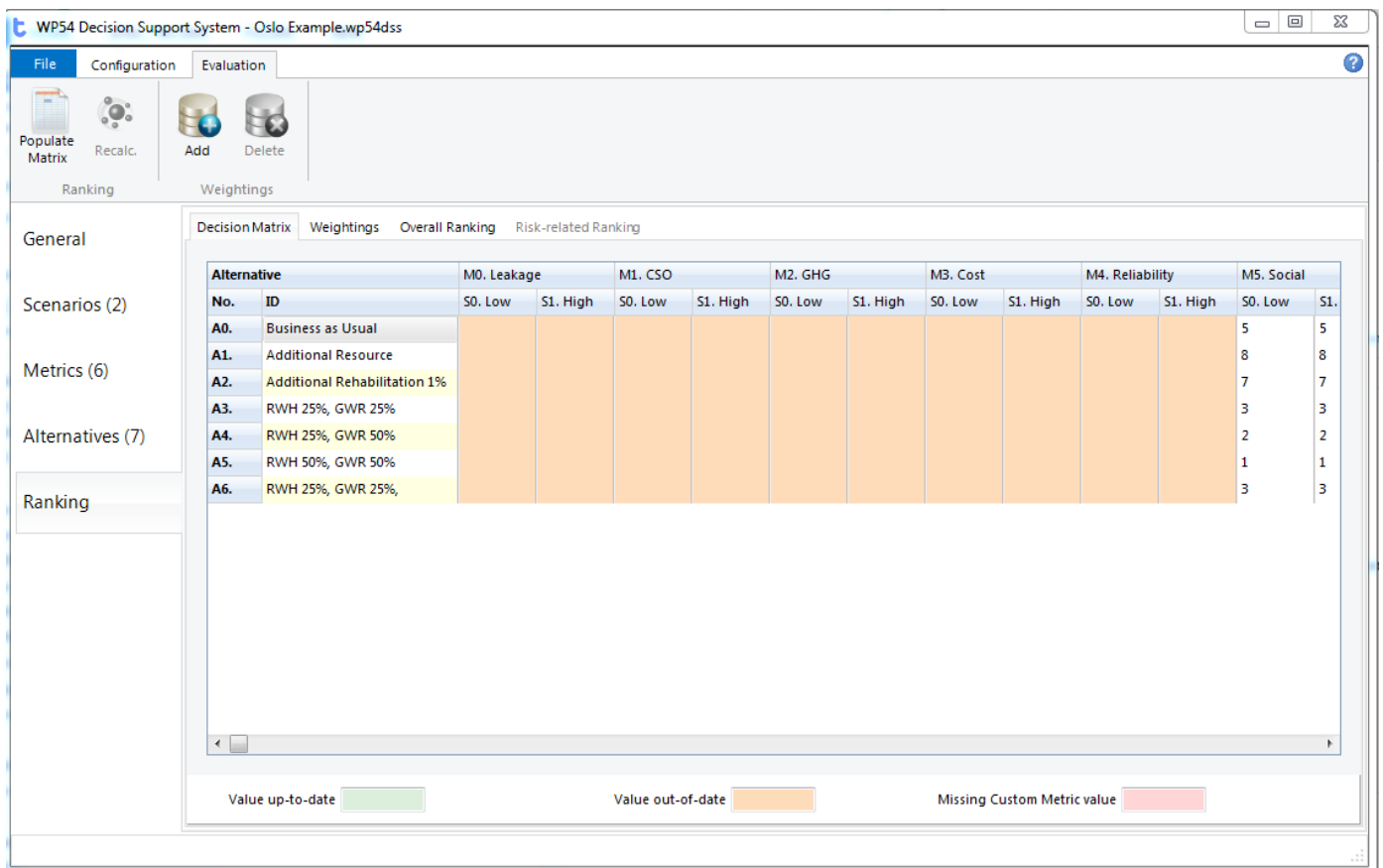


Figure 4.10 DSS Decision matrix

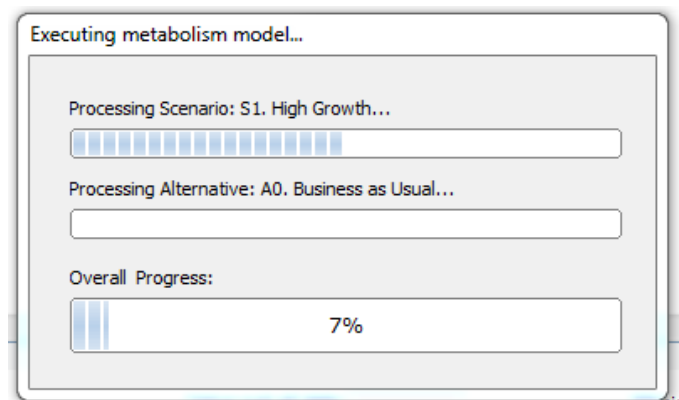


Figure 4.11 Form representing the running DSS

After fully completing the decision matrix, the user can define new sets of weighting schemes for the performance metrics which represent the preference weightings employed in the Compromise Programming side of the MCDA analysis. Clicking the “Add” button in the Evaluation ribbon as shown in Figure 4.12 allows the user to specify a new weighting scheme. The Equal Weighting scheme (the default) cannot be changed or deleted. Note that if the user changes any of the input data for the weightings, the performance metrics need to be recalculated which can be done using “Recalculate” button in the Evaluation ribbon.

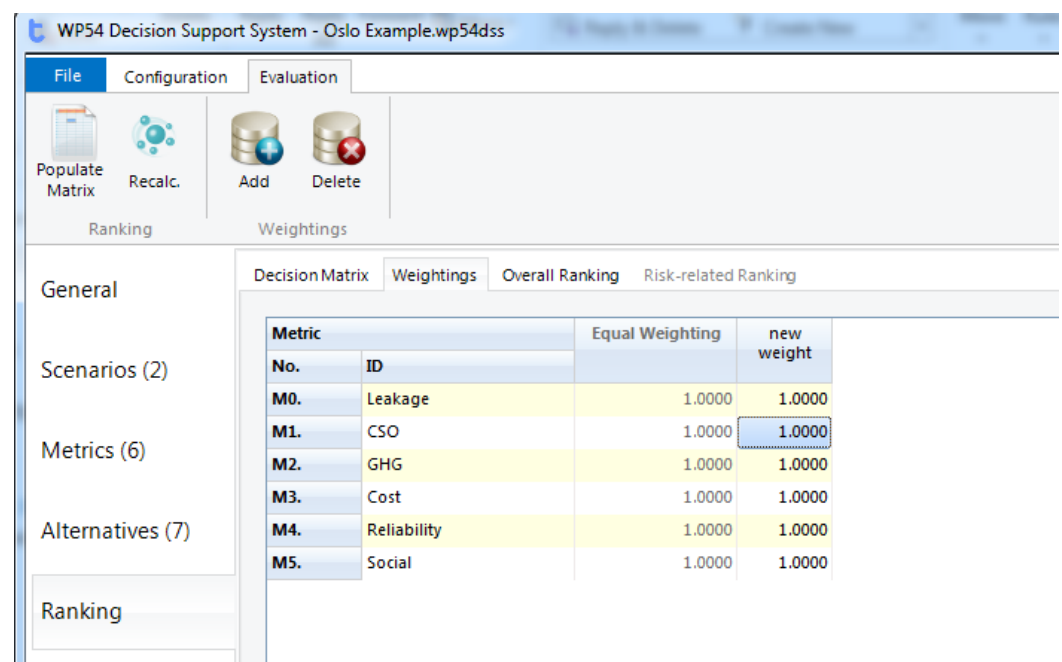


Figure 4.12 New weighting scheme

4.1.4. Retrieval of Results

Following the specification of any additional weighting schemes required, based on the preferences of stakeholders, the ranking of intervention strategies can be performed in the DSS. The ranking is displayed in the ‘Overall Ranking’ tab of the ‘Ranking’ section when the “Recalculate” button is pressed (Figure 4.13). The final ranking is then calculated by the DSS using the MCDA method requested. The ranking is shown in the relevant table based on the sum of the ranking for each weighting scheme and scenario (a sample of which is shown in Figure 4.14).

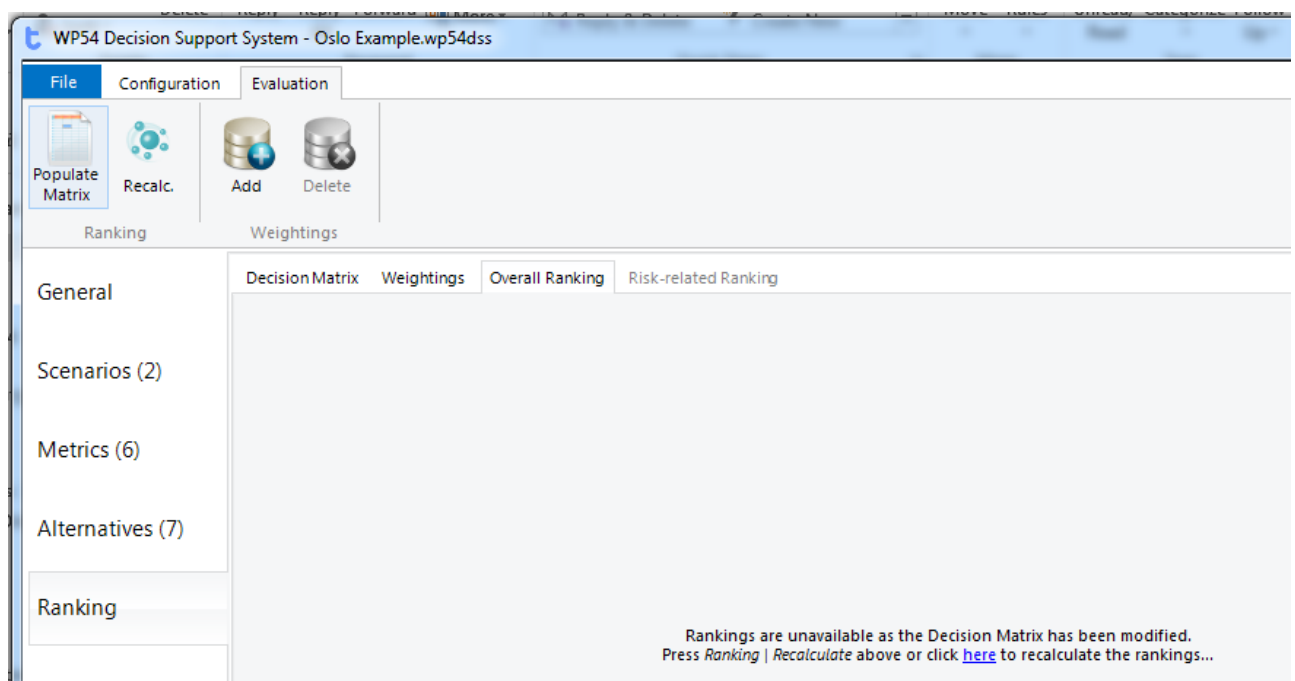


Figure 4.13 Overall ranking form in the DSS

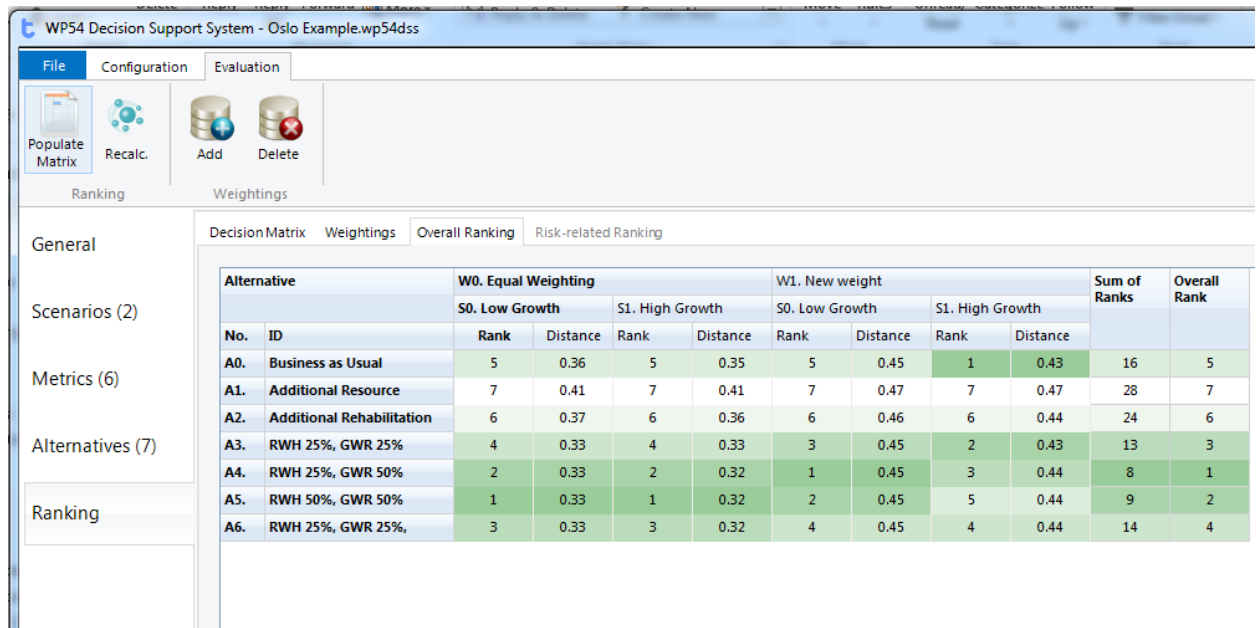


Figure 4.14 Ranking form of a number of intervention strategies

4.2. Web-based Tool

4.2.1. Getting started

The web-based version of the DSS is part of the TRUST software deployment, which can be accessed at the following web address: <http://trust.baseform.org> (Figure 4-15).

The same access credentials (username/password) used for TRUST's project intranet site should be used for logging on to the software. A User Guide (Vitorino and Coelho, 2015) is available for a step-by-step introduction to the software.

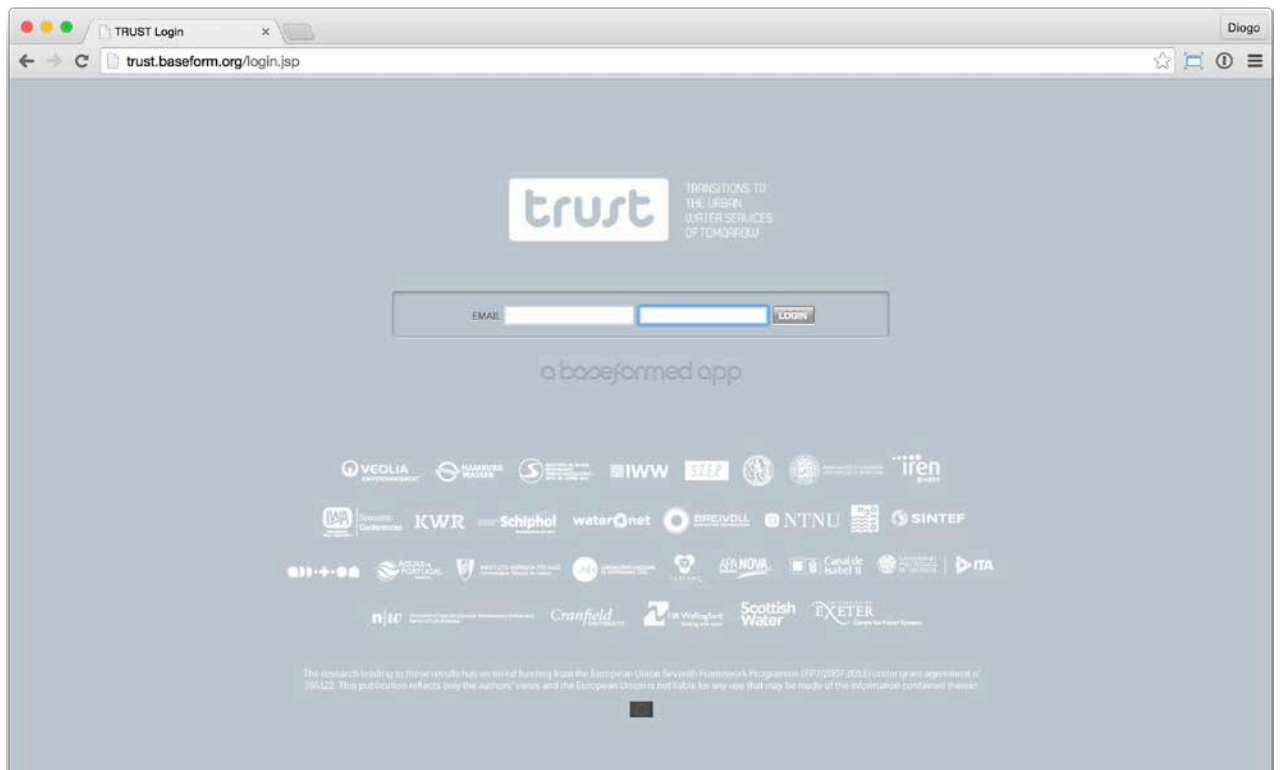


Figure 4.15 First webpage of the TRUST DSS

System requirements

The software runs on any updated web browser, from any machine that can access the web, such as a Windows/Mac personal computer, an iPad or other tablet. For best results, it is advisable to use the Google Chrome® web browser.

Analysis prerequisites

The user can either base the analysis on an existing WaterMet² model, or start a new manual problem definition, not based on a WaterMet² model. It is also possible to carry out a mixed analysis that involves both:

- WaterMet² -defined scenarios, alternatives and metrics, and
- manually-defined scenarios, alternatives and metrics.

The DSS, when used in conjunction with WaterMet², relies on an existing WaterMet² XML model, developed and calibrated externally to the software web-based tool; the XML model includes the overall metabolism model, components, behaviours, indicators and pre-set

alternatives (intervention strategies) and scenarios. The web-based DSS application invokes and interacts with WaterMet² results through the WaterMet² XML Interface software included and residing in the web application server in common with the desktop tool.

The Quick Start screen

The TRUST software deployment includes a range of pre-existing tools from the Baseform platform, and hosts the new, TRUST-developed tools, organized by work package on the tool list, found on the left side of the main screen. The software opens in the **Quickstart** menu, offering quick links to the most recent analyses and to help tools. New users are advised to read both guides available (*Data Manager Quickstart Guide* and the *How to upload, backup and restore files Guide*), in order to become familiar with the file system and the Data Manager in this cloud-based environment.

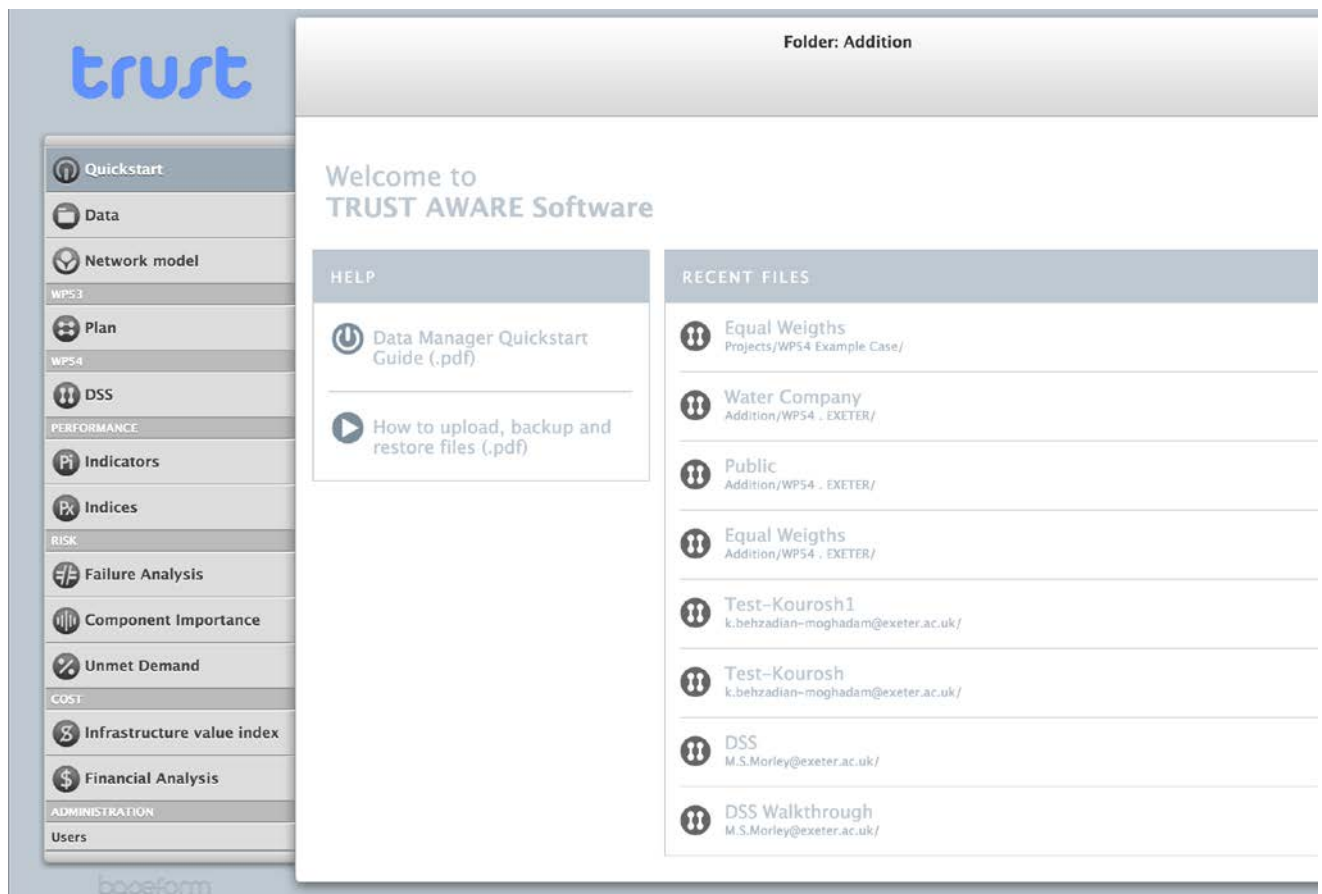


Figure 4.16 Main form of web-based DSS

Using the DSS

When clicking on the DSS application (on the tool list on the left), a list is shown of DSS analysis files available in the folder selected (drop-down menu on top). It is also possible to list all available DSS analysis files by checking the **Search everywhere** option at the top. Each existing file is displayed with a summary of key analysis information. Any number of analyses, data and files can be created both for private use and for collaborative work.

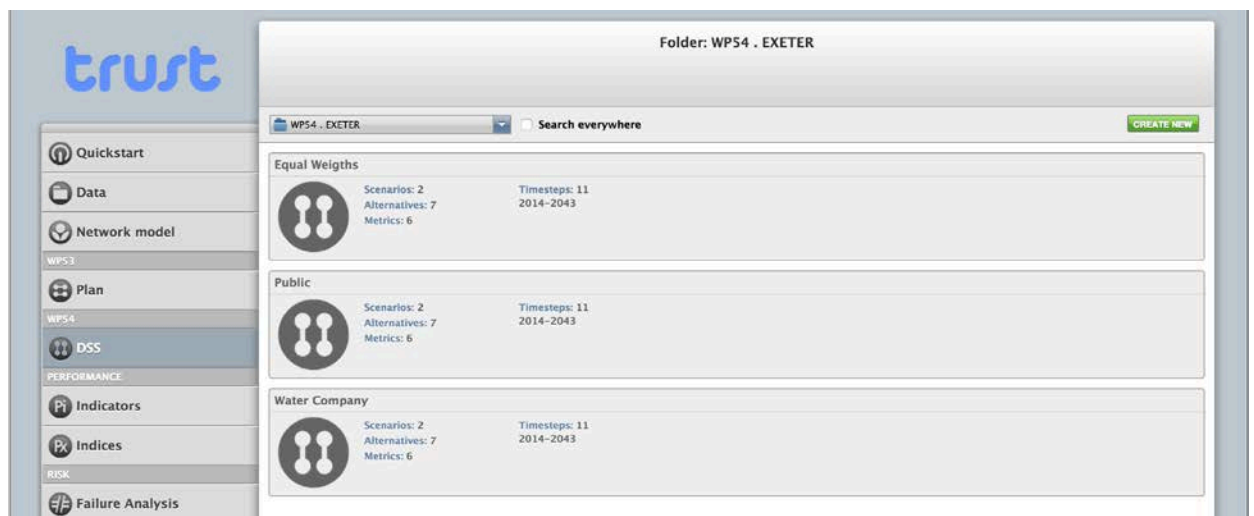


Figure 4.17 Tool list of the web-based DSS

Click on the **Create New** button (top right) to start a new DSS analysis. Begin by naming the DSS analysis file.

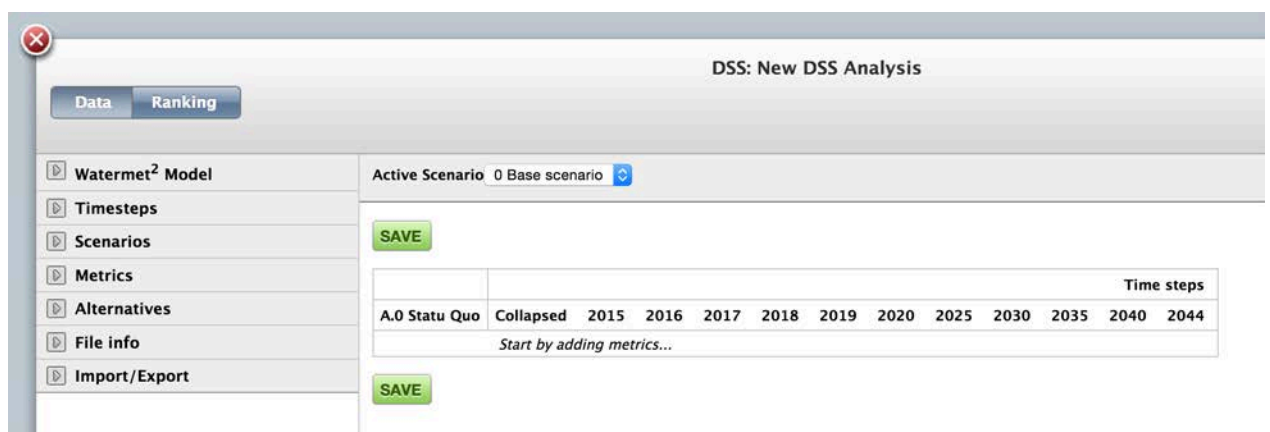


Figure 4.18 Creating New file in web-based DSS

The software has a list of ‘drawers’ on the left side that correspond to the main menu items for its use. The first five represent the main steps in adding data and configuring an analysis in this web-based version of the DSS:

- WaterMet² Model (if used)
- Timesteps
- Scenarios
- Metrics
- Alternatives

The **Data** tab displays the main DSS decision matrix, with values for each metric at each time step for each alternative. The various alternatives are organized in blocks of data that can be viewed by scrolling down. User-defined metrics are directly editable in this matrix.

The top drawer on the left allows for selecting a WaterMet² model file (extension .xml). The WaterMet² model file must have been previously uploaded to the platform. In case the user is not familiar with how to perform this operation, it is advisable to read the *Data Manager Quickstart Guide* and the *How to upload, backup and restore files* Guide available in pdf format from the **QuickStart** menu. The model files available in the folder selected are listed. Click on the file name to select it.

The system reads the WaterMet² model-generated data, displays the number of existing scenarios, alternatives and metrics, and allows for importing all WaterMet² scenarios and alternatives.

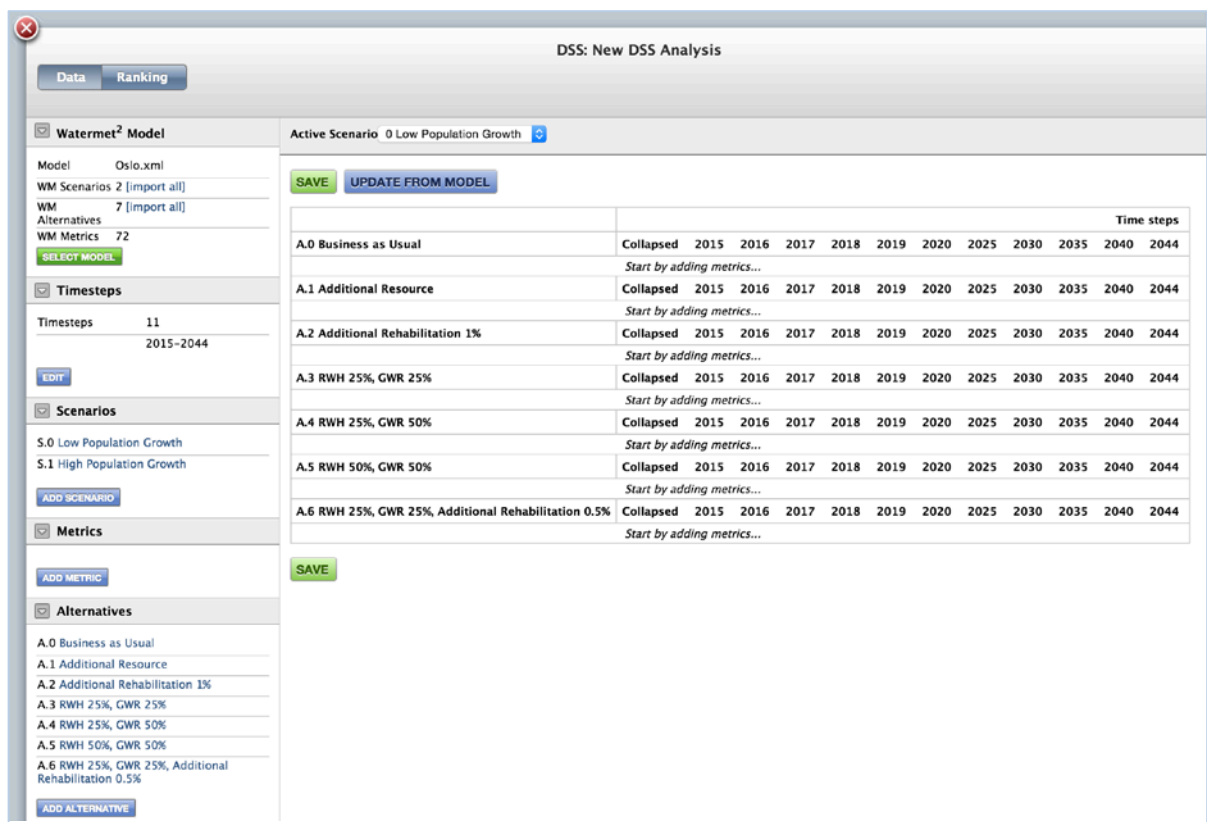


Figure 4.19 Opened existing file in web-based DSS

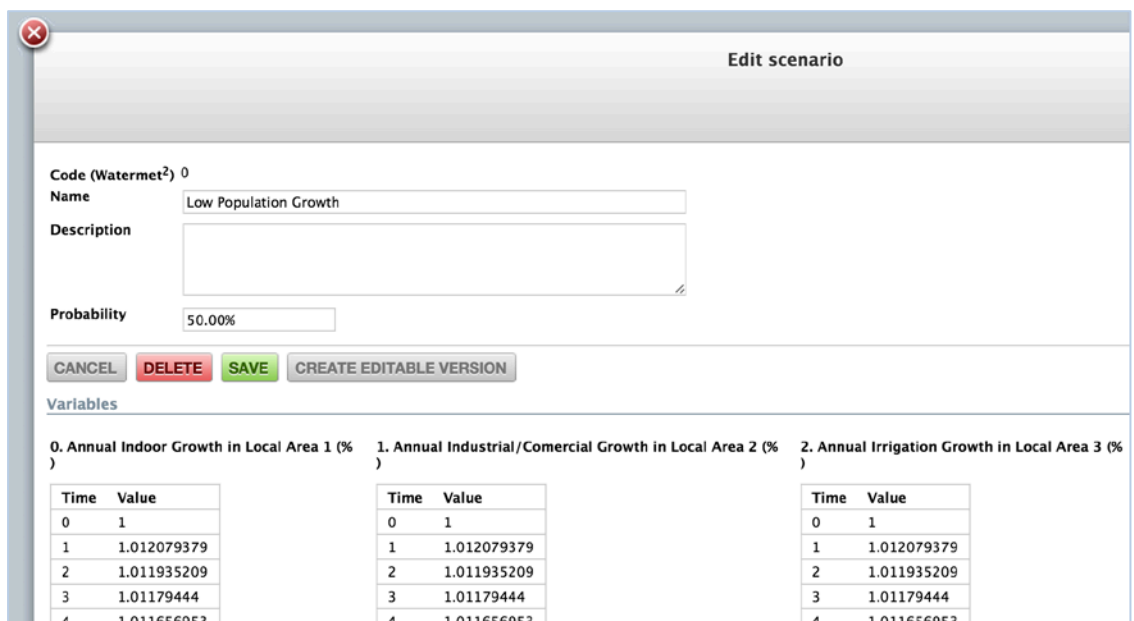
4.2.2. Overview of data forms

Timesteps

The DSS automatically creates a default 30-year time span, starting with five 1-year steps and five 5-year additional steps. The user can add or remove time steps directly.

Scenarios

WaterMet²-generated scenarios (i.e., not defined by the user in this software) display variables and values. Editing can be performed by creating a new editable scenario, which imports data from a base WaterMet² scenario and allows for changing variable values.



Edit scenario

Code (Watermet²) 0

Name

Description

Probability

Variables

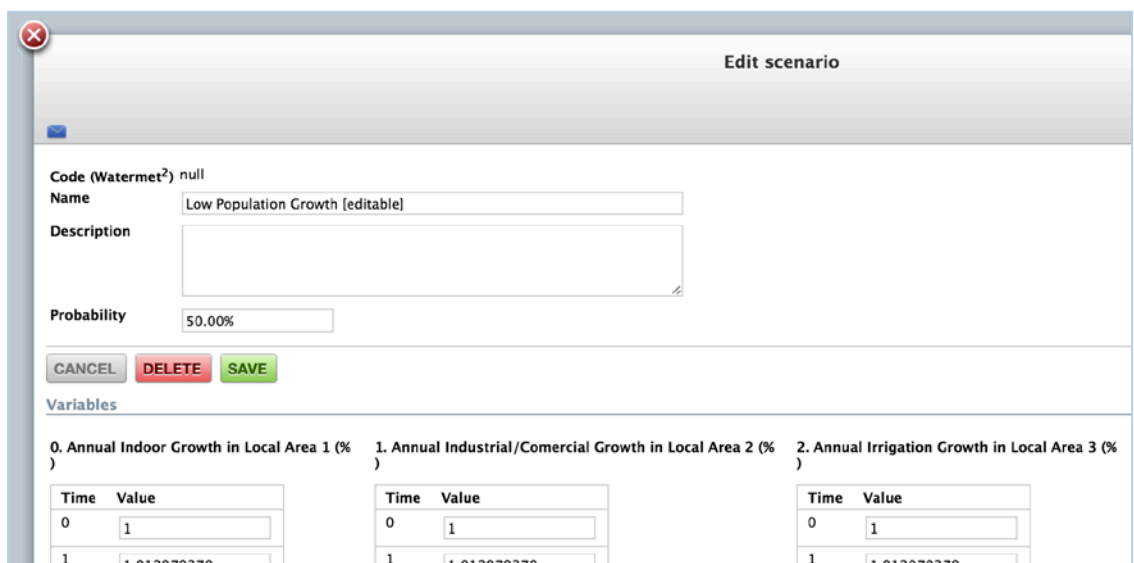
0. Annual Indoor Growth in Local Area 1 (%) 1. Annual Industrial/Comercial Growth in Local Area 2 (%) 2. Annual Irrigation Growth in Local Area 3 (%)

Time	Value
0	1
1	1.012079379
2	1.011935209
3	1.01179444
4	1.011656953

Time	Value
0	1
1	1.012079379
2	1.011935209
3	1.01179444
4	1.011656953

Time	Value
0	1
1	1.012079379
2	1.011935209
3	1.01179444
4	1.011656953

Figure 4.20 Edit scenario in web-based DSS



Edit scenario

Code (Watermet²) null

Name

Description

Probability

Variables

0. Annual Indoor Growth in Local Area 1 (%) 1. Annual Industrial/Comercial Growth in Local Area 2 (%) 2. Annual Irrigation Growth in Local Area 3 (%)

Time	Value
0	<input type="text" value="1"/>
1	<input type="text" value="1.012079379"/>

Time	Value
0	<input type="text" value="1"/>
1	<input type="text" value="1.012079379"/>

Time	Value
0	<input type="text" value="1"/>
1	<input type="text" value="1.012079379"/>

Figure 4.21 Edit scenario in web-based DSS

Non-WaterMet² scenarios are also available by choosing **Add scenario** from the **Scenarios** drawer on the left side of the application's main screen. Any number of scenarios can be created. The metric's values for user-defined scenarios must be manually entered.



Edit scenario

Code: 02

Name: Test Scenario X

Description: [Empty text area]

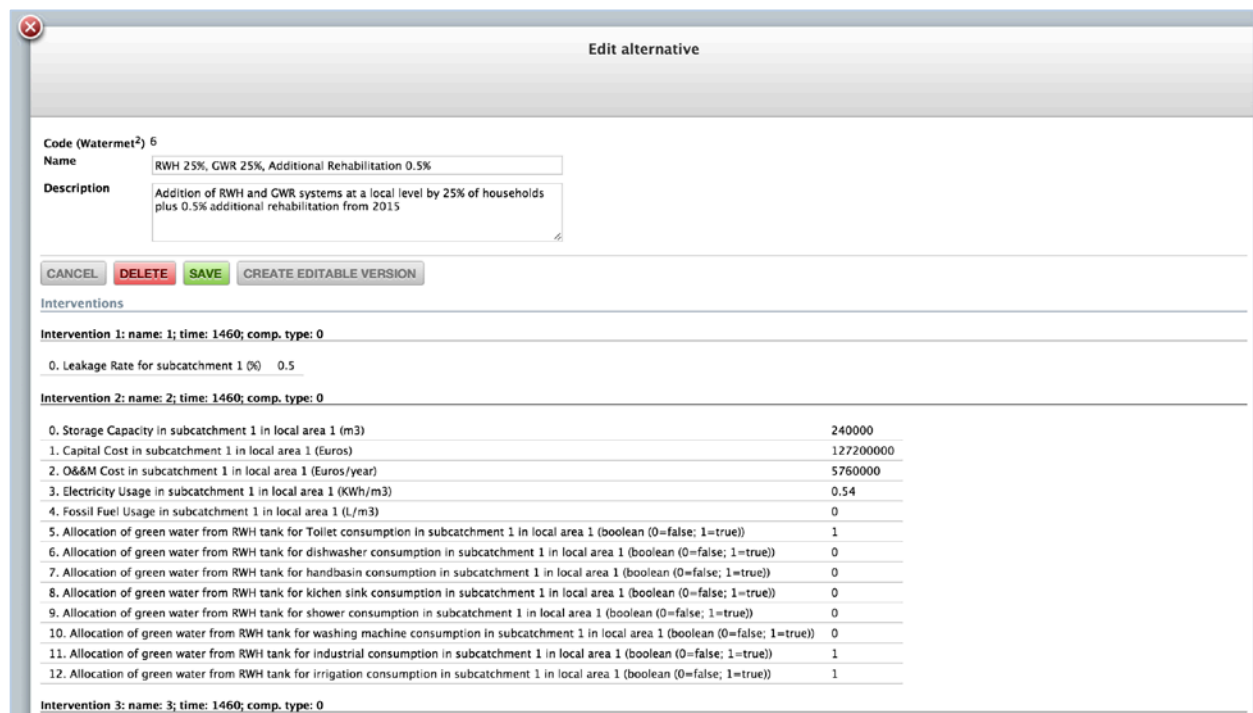
Probability: 12.00%

CANCEL DELETE SAVE

Figure 4.22 Adding scenario in web-based DSS

Alternatives

WaterMet² alternatives (i.e., not defined by the user in this software) display model variables and values, listed per individual intervention.



Edit alternative

Code (Watermet²): 6

Name: RWH 25%, GWR 25%, Additional Rehabilitation 0.5%

Description: Addition of RWH and GWR systems at a local level by 25% of households plus 0.5% additional rehabilitation from 2015

CANCEL DELETE SAVE CREATE EDITABLE VERSION

Interventions

Intervention 1: name: 1; time: 1460; comp. type: 0

- 0. Leakage Rate for subcatchment 1 (%) 0.5

Intervention 2: name: 2; time: 1460; comp. type: 0

0. Storage Capacity in subcatchment 1 in local area 1 (m3)	240000
1. Capital Cost in subcatchment 1 in local area 1 (Euros)	127200000
2. O&M Cost in subcatchment 1 in local area 1 (Euros/year)	5760000
3. Electricity Usage in subcatchment 1 in local area 1 (KWh/m3)	0.54
4. Fossil Fuel Usage in subcatchment 1 in local area 1 (L/m3)	0
5. Allocation of green water from RWH tank for Toilet consumption in subcatchment 1 in local area 1 (boolean (0=false; 1=true))	1
6. Allocation of green water from RWH tank for dishwasher consumption in subcatchment 1 in local area 1 (boolean (0=false; 1=true))	0
7. Allocation of green water from RWH tank for handbasin consumption in subcatchment 1 in local area 1 (boolean (0=false; 1=true))	0
8. Allocation of green water from RWH tank for kitchen sink consumption in subcatchment 1 in local area 1 (boolean (0=false; 1=true))	0
9. Allocation of green water from RWH tank for shower consumption in subcatchment 1 in local area 1 (boolean (0=false; 1=true))	0
10. Allocation of green water from RWH tank for washing machine consumption in subcatchment 1 in local area 1 (boolean (0=false; 1=true))	0
11. Allocation of green water from RWH tank for industrial consumption in subcatchment 1 in local area 1 (boolean (0=false; 1=true))	1
12. Allocation of green water from RWH tank for irrigation consumption in subcatchment 1 in local area 1 (boolean (0=false; 1=true))	1

Intervention 3: name: 3; time: 1460; comp. type: 0

Figure 4.23 Editing alternative in web-based DSS

In a similar manner to Scenarios, editing can be carried out by creating a new editable version of a given WaterMet² alternative, which imports its data and allows for the variable values to be changed.

Similarly to Scenarios, non-WaterMet² alternatives are also available by choosing **Add alternative** from the **Alternatives** drawer on the left side of the application's main screen. Any number of alternatives can be created. The metric's values for user-defined alternatives must be manually entered.

Metrics

The WaterMet²-generated models include metrics which, like the scenarios and the alternatives, have been defined outside of this software. The user must add metrics by pressing the **Add metric** from the **Metric** drawer on the left side of the application's main screen, and deselecting the **User defined** checkbox. A list of the metrics available in the selected WaterMet² model will become available.

Upon selecting a metric, it may be further qualified by the user through the definition of (i) an evaluation strategy (min, max or annual targets); (ii) a weight; a (iii) a collapsing method; (iv) an aggregation method; and (v) a resampling method.

User-defined Metrics, (i.e., non- WaterMet² generated metrics) can also be used, choosing **Add metric** from the **Metric** drawer and keeping the **User defined** checkbox on. Any number of user-defined metrics may be added. The alternative-assessment values for user-defined metrics must be manually entered.

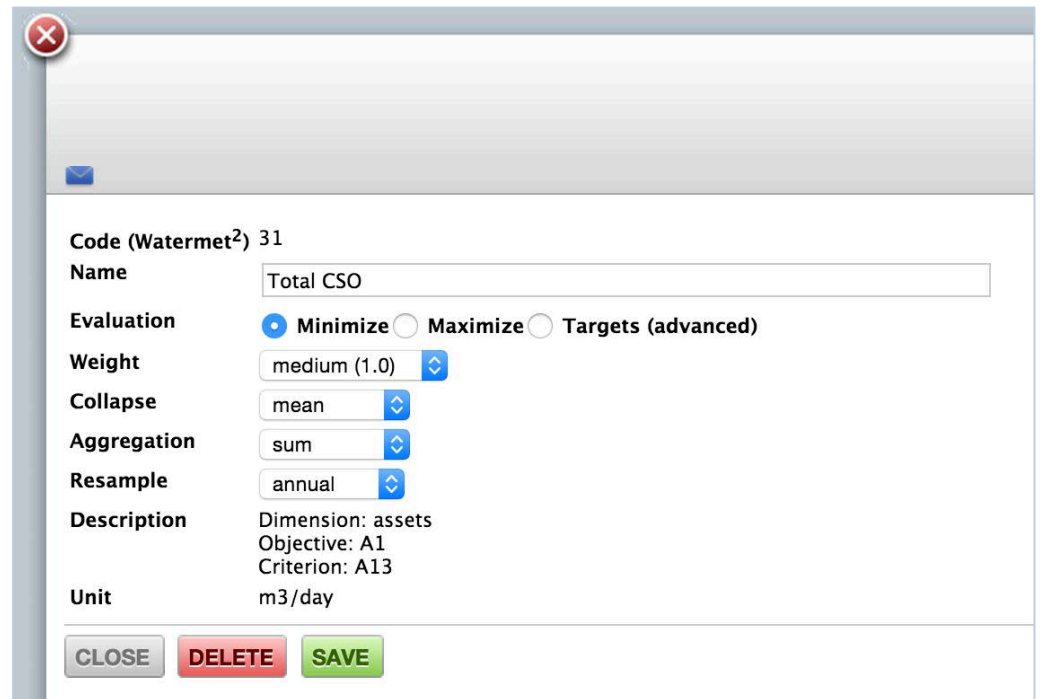


Figure 4.24 Editing metrics in web-based DSS

4.2.3. Running the DSS

WaterMet² Simulation

Selecting “update from model” runs a full WaterMet² model simulation for each WaterMet² scenario and alternative, (re)populating the data matrix.

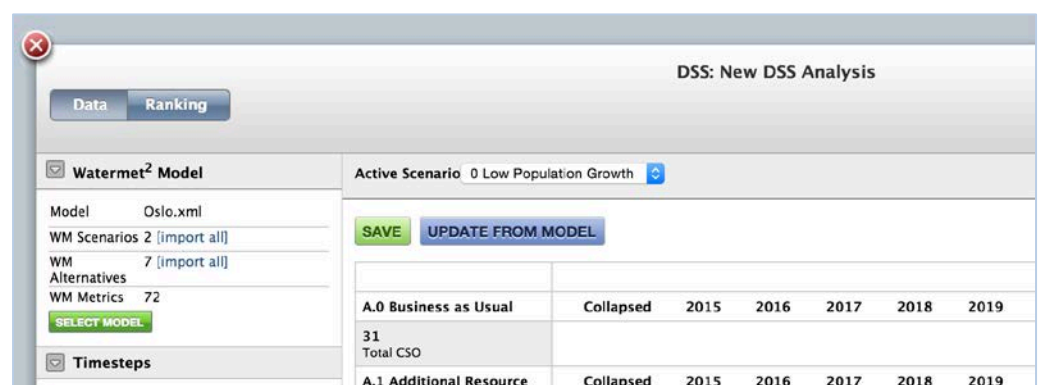


Figure 4.25 Web-based DSS ready for simulation



Figure 4.26 Simulation in progress for web-based DSS

A simulation log is provided (top left, in the WaterMet² drawer) to provide feedback on runtimes and simulation-specific markers.

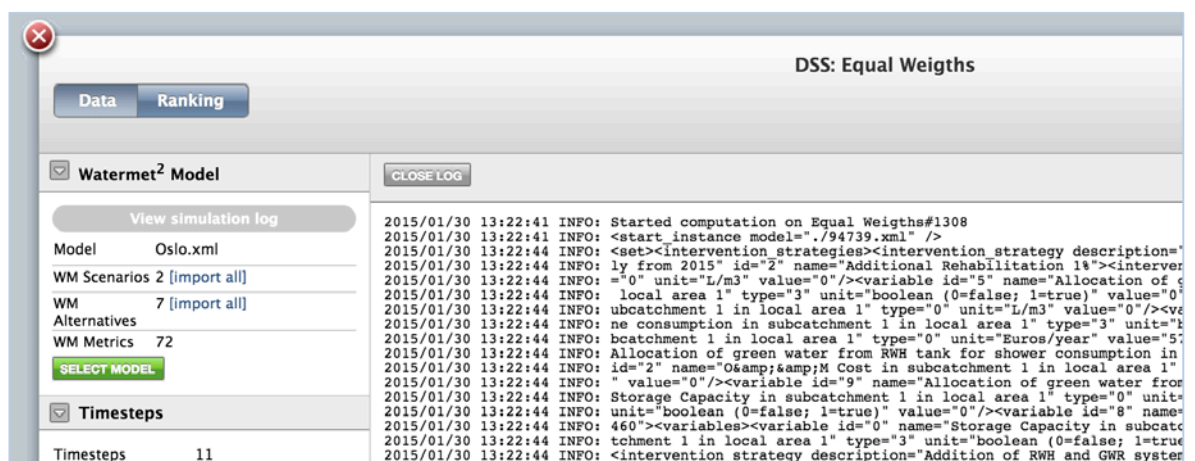


Figure 4.27 Result page of the web-based DSS

The DSS data matrix is presented in the main application screen (below) for each scenario. The scenario selector is located at the top of the screen and allows for retrieving the matrix for each scenario. The matrix shows the values of each metric at each time step, for each alternative, in successive blocks of data for each individual alternative. Scrolling down allow for examining the various alternatives.

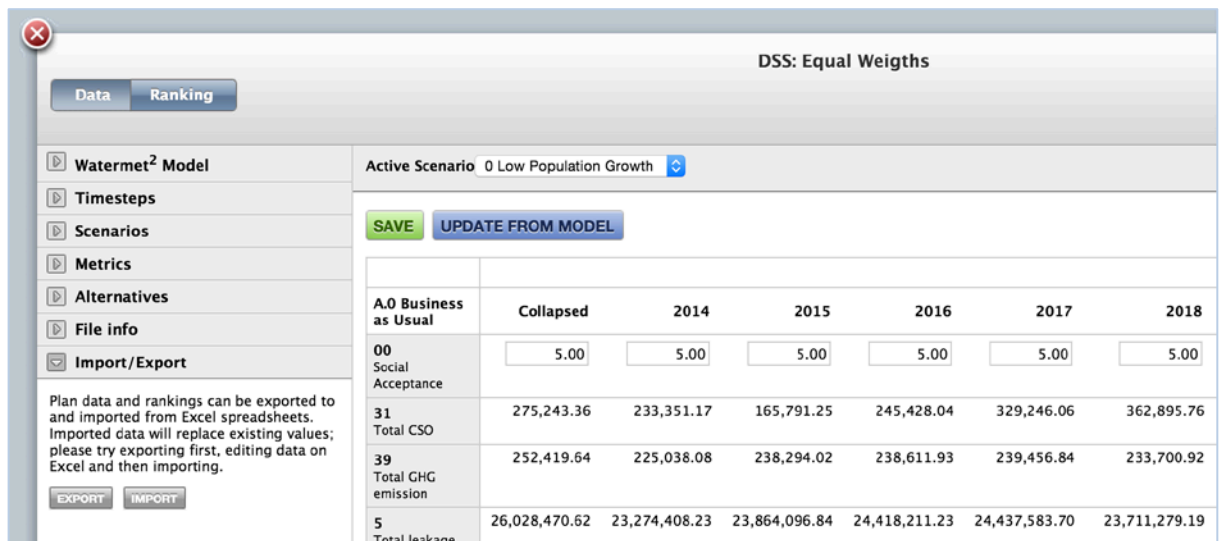


Figure 4.28 Metrics over the different years of planning horizon

Exporting/importing the DSS matrix to/from MS Excel®

The DSS data matrix may be exported to, and/ imported from a preset MS Excel® file format which is designed to make it easier to manipulate larger amounts of data, or to carry the values to other software. It is possible to export, modify and then import back again the same workbook file.

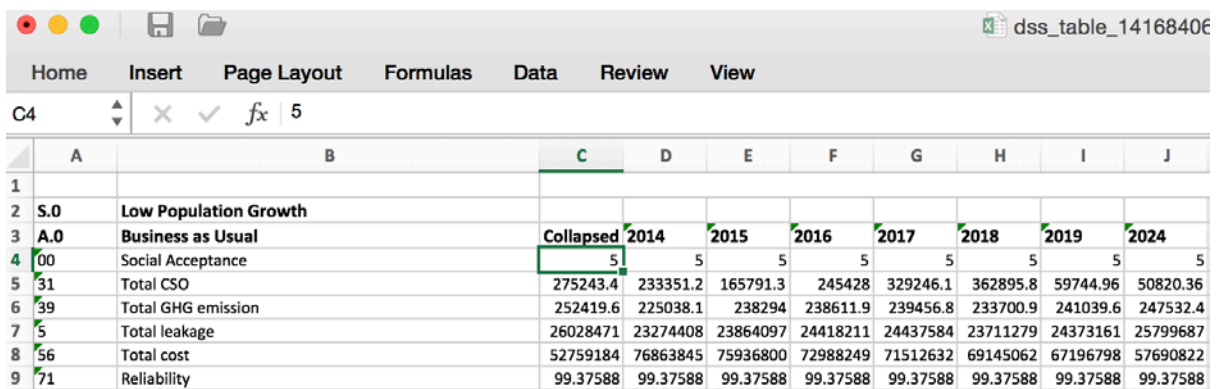


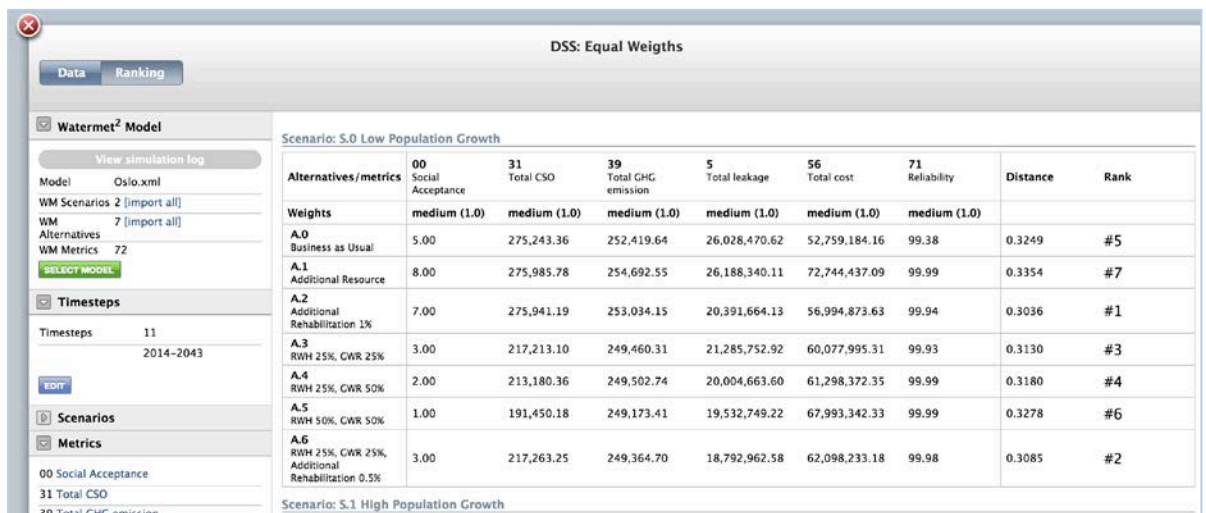
Figure 4.29 Exporting DSS matrix to MS Excel

4.2.4. Retrieval of results

Ranking of alternatives

Ranking results are generated by invoking in the background a MCDA software module which operates on the decision matrix and problem definition (ranking criteria and metric properties).

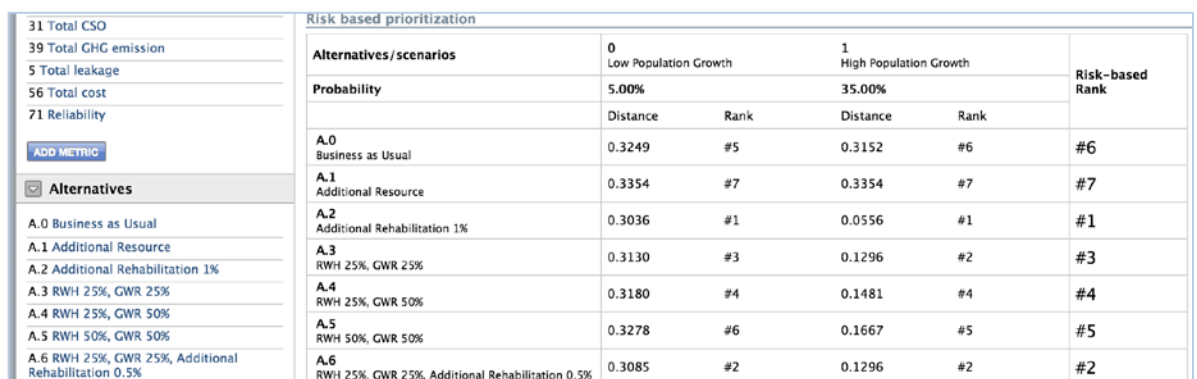
The **Ranking** tab displays results on a matrix of Alternatives vs. Metrics, including relative rank, and distance. The user can scroll the table to view all of the scenarios.



DSS: Equal Weights								
Watermet ² Model		Scenario: S.0 Low Population Growth						
Alternatives/metrics	00 Social Acceptance	31 Total CSO	39 Total GHG emission	5 Total leakage	56 Total cost	71 Reliability	Distance	Rank
Weights	medium (1.0)	medium (1.0)	medium (1.0)	medium (1.0)	medium (1.0)	medium (1.0)		
A.0 Business as Usual	5.00	275,243.36	252,419.64	26,028,470.62	52,759,184.16	99.38	0.3249	#5
A.1 Additional Resource	8.00	275,985.78	254,692.55	26,188,340.11	72,744,437.09	99.99	0.3354	#7
A.2 Additional Rehabilitation 1%	7.00	275,941.19	253,034.15	20,391,664.13	56,994,873.63	99.94	0.3036	#1
A.3 RWH 25%, GWR 25%	3.00	217,213.10	249,460.31	21,285,752.92	60,077,995.31	99.93	0.3130	#3
A.4 RWH 25%, GWR 50%	2.00	213,180.36	249,502.74	20,004,663.60	61,298,372.35	99.99	0.3180	#4
A.5 RWH 50%, GWR 50%	1.00	191,450.18	249,173.41	19,532,749.22	67,993,342.33	99.99	0.3278	#6
A.6 RWH 25%, GWR 25%, Additional Rehabilitation 0.5%	3.00	217,263.25	249,364.70	18,792,962.58	62,098,233.18	99.98	0.3085	#2

Figure 4.30 Ranking of alternatives

At the bottom of the table, a risk-based, cross-scenario alternative ranking is presented.



Alternatives/scenarios	Risk based prioritization				Risk-based Rank	
	0 Low Population Growth		1 High Population Growth			
	Probability	Distance	Rank	Distance		Rank
A.0 Business as Usual	5.00%	0.3249	#5	0.3152	#6	#6
A.1 Additional Resource		0.3354	#7	0.3354	#7	#7
A.2 Additional Rehabilitation 1%		0.3036	#1	0.0556	#1	#1
A.3 RWH 25%, GWR 25%		0.3130	#3	0.1296	#2	#3
A.4 RWH 25%, GWR 50%		0.3180	#4	0.1481	#4	#4
A.5 RWH 50%, GWR 50%		0.3278	#6	0.1667	#5	#5
A.6 RWH 25%, GWR 25%, Additional Rehabilitation 0.5%		0.3085	#2	0.1296	#2	#2

Figure 4.31 Risk based representation

Different weightings

Analyzing different weightings is possible by creating *cloned* versions of the problem definition and modifying the weighting system used for the metrics. This is accomplished by copying the intended DSS analysis file in the Data environment, renaming it to reflect the new parameters, and opening the file from the DSS tool to carry out the necessary changes.

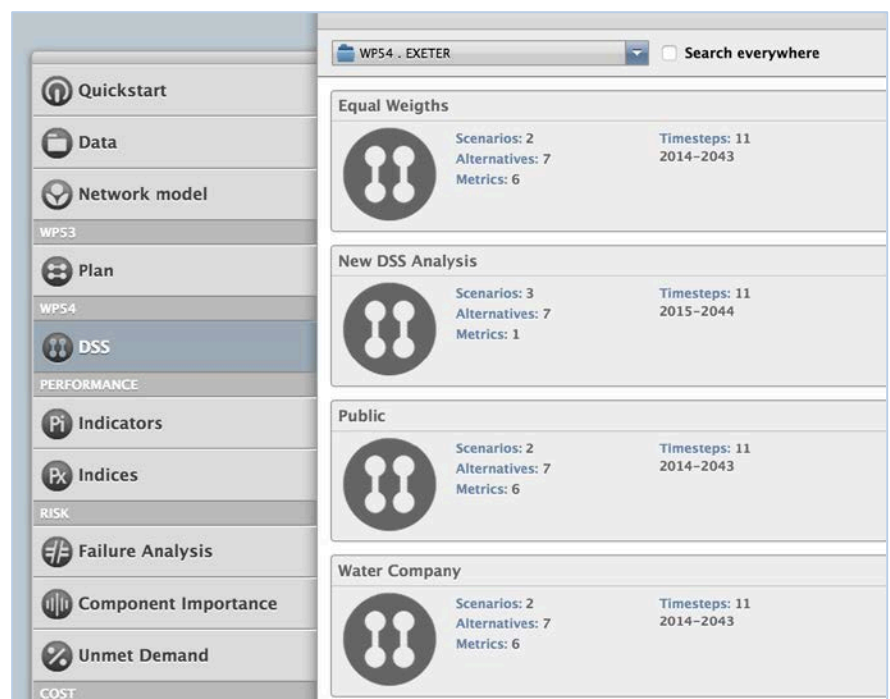


Figure 4.32 Different weighting in web-based DSS

5. CASE STUDY

The two DSS software tools are demonstrated below on a northern European real-life case study. It should be noted that this case study is inspired by, although not completely representative of, the UWS of a northern European city. This is because the reference city modelled and analysed here is not fully configured for the real case study as full access to the UWS data could not be provided during the project owing to client confidentiality. Hence, the analysis conducted and the corresponding results obtained in this report do not reflect the views of the relevant water company and have been used only to demonstrate the possible application and functionality of the DSS software tools. Therefore, this UWS is used here merely as a reference city for the case study combined with assumptions where necessary.

This UWS will face a number of challenges, among which population growth is likely to impose significant stresses on the UWS performance in the future. As a consequence, it is predicted that the city population of ~750,000 inhabitants in 2014 will reach approximately 1,240,000 inhabitants in 2045 taking the highest anticipated rate of population growth.

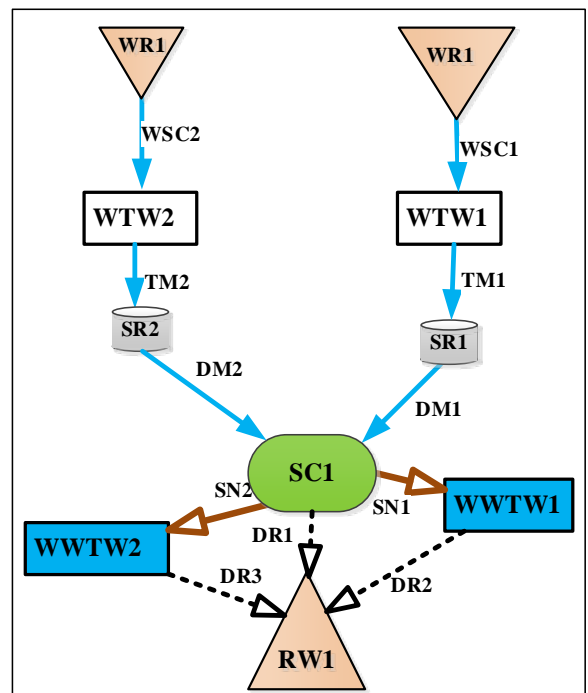


Figure 5.1 Layout of the main components in the UWS for existing conditions

Note that WR=water resource, WSC=water supply conduit, WTW=water treatment works, TM=trunk main, SR=service reservoir, DM=distribution main, SC=subcatchment, SN=sewer network, WWTW=waste water treatment works, DR=discharge route, RW=receiving water,

The DSS tool for the strategic planning of an integrated urban water system (UWS) over a pre-defined long-term planning horizon is presented here. The DSS evaluates and ranks a number of user defined alternative intervention strategies (IS or simply alternatives) by evaluating their impact on a number of (user-defined) UWS performance metrics, all for a number of (user-defined) scenarios.

5.1. Problem description

The data requirements for the specification for the scenarios, performance metrics, intervention strategies (alternatives) and stakeholder preferences are outlined in the following section.

5.1.1. Scenarios

This UWS is likely to face the challenge of population growth in the future which, naturally, will result in increased water demand. Two rates of future population growth (i.e. low and high) have been envisaged for a 30 year planning period starting from 2010. The time series of annual factors for these two rates of population growth and associated water demands in the UWS over the planning horizon are given in Table 3 and Table 4.

Table 3. Time series of annual factors for low rate of population growth and associated two water demands in the UWS

SCENARIO VARIABLES	ANNUAL POPULATION GROWTH FACTOR	ANNUAL INDUSTRIAL WATER DEMAND GROWTH FACTOR	ANNUAL IRRIGATION WATER DEMAND GROWTH FACTOR
Units	-	-	-
Year 2011	1.0000	1.0000	1.0000
Year 2012	1.0121	1.0116	1.0111
Year 2013	1.0119	1.0114	1.0109
Year 2014	1.0118	1.0113	1.0108
Year 2015	1.0117	1.0112	1.0107
Year 2016	1.0115	1.0110	1.0105
Year 2017	1.0114	1.0109	1.0104
Year 2018	1.0113	1.0108	1.0103
Year 2019	1.0111	1.0106	1.0101
Year 2020	1.0110	1.0105	1.0100
Year 2021	1.0109	1.0104	1.0099
Year 2022	1.0108	1.0103	1.0098
Year 2023	1.0107	1.0102	1.0097
Year 2024	1.0106	1.0101	1.0096
Year 2025	1.0104	1.0099	1.0094
Year 2026	1.0103	1.0098	1.0093
Year 2027	1.0102	1.0097	1.0092
Year 2028	1.0101	1.0096	1.0091
Year 2029	1.0100	1.0095	1.0090
Year 2030	1.0099	1.0094	1.0089
Year 2031	1.0013	1.0008	1.0003
Year 2032	1.0013	1.0008	1.0003
Year 2033	1.0013	1.0008	1.0003
Year 2034	1.0013	1.0008	1.0003
Year 2035	1.0013	1.0008	1.0003
Year 2036	1.0013	1.0008	1.0003
Year 2037	1.0013	1.0008	1.0003
Year 2038	1.0013	1.0008	1.0003
Year 2039	1.0013	1.0008	1.0003
Year 2040	1.0013	1.0008	1.0003

Table 4. Time series of annual factors for high rate of population growth and associated two water demands in the UWS

SCENARIO VARIABLES	ANNUAL POPULATION GROWTH	ANNUAL INDUSTRIAL WATER DEMAND GROWTH	ANNUAL IRRIGATION WATER DEMAND GROWTH
Units	-	-	-
Year 2011	1.0000	1.0000	1.0000
Year 2012	1.0240	1.0235	1.0230
Year 2013	1.0230	1.0225	1.0220
Year 2014	1.0230	1.0225	1.0220
Year 2015	1.0220	1.0215	1.0210
Year 2016	1.0220	1.0215	1.0210
Year 2017	1.0210	1.0205	1.0200
Year 2018	1.0210	1.0205	1.0200
Year 2019	1.0200	1.0195	1.0190
Year 2020	1.0200	1.0195	1.0190
Year 2021	1.0200	1.0195	1.0190
Year 2022	1.0190	1.0185	1.0180
Year 2023	1.0190	1.0185	1.0180
Year 2024	1.0180	1.0175	1.0170
Year 2025	1.0180	1.0175	1.0170
Year 2026	1.0180	1.0175	1.0170
Year 2027	1.0170	1.0165	1.0160
Year 2028	1.0170	1.0165	1.0160
Year 2029	1.0170	1.0165	1.0160
Year 2030	1.0170	1.0165	1.0160
Year 2031	1.0140	1.0135	1.0130
Year 2032	1.0140	1.0135	1.0130
Year 2033	1.0130	1.0125	1.0120
Year 2034	1.0130	1.0125	1.0120
Year 2035	1.0130	1.0125	1.0120
Year 2036	1.0130	1.0125	1.0120
Year 2037	1.0130	1.0125	1.0120
Year 2038	1.0130	1.0125	1.0120
Year 2039	1.0120	1.0115	1.0110
Year 2040	1.0120	1.0115	1.0110

5.1.2. Performance metrics

According to the performance criteria of sustainability dimensions of water systems (Alegre *et al.*, 2012), six performance metrics are considered for this analysis. These metrics include five quantitative criteria (M0-M4), and a single qualitative criterion, M5. A brief description of these metrics is outlined below:

- M0. Reliability of water supply:** the ratio of water delivered to customers to the total water demand.
- M1. Total cost:** annual average of the discounted initial capital investment of interventions plus discounted value of the fixed and variable costs in different UWS components to the first year with a specific discount rate.
- M2. GHG emissions:** annual average of the aggregated greenhouse gas emissions (GHG), as Global Warming Potential (GWP100) measured in units of carbon dioxide equivalents (CO₂-eq) from all components of the UWS.
- M3. Leakage:** Annual average of leakage volume is measured in all conveyance components of water supply assuming leakage is a fixed percentage of water supply in water supply conveyance components.
- M4. CSO volume:** Annual average of spill volume of CSOs (combined sewer overflow) is measured when daily flow in sewer network exceeds the capacity of a CSO structure.
- M5. Social acceptance:** the extent to which an intervention strategy would be supported by society, especially water consumers; in order to fulfil the water demands with respect to a number of factors especially safety and health issues.

The main features of these six performance metrics which will be required for the DSS are summarised in Table 5.

Table 5. Specifications of the performance metrics for the case study

ID	DESCRIPTION	PERFORMANCE METRIC			QUANTIFICATION	GOAL	NORMALISATION VALUES
		Component	Component ID	Units			
M0	Reliability of water supply/demand balance	UWS	0	%	WaterMet ²	Optimization (max)	-
M1	Total cost	UWS	0	Euros/year	WaterMet ²	Optimization (min)	-
M2	GHG emissions	UWS	0	Tons/year	WaterMet ²	Optimization (min)	-
M3	Leakage	UWS	0	m ³ /year	WaterMet ²	Optimization (min)	-
M4	CSO volume	UWS	0	Tons/year	WaterMet ²	Optimization (min)	-
M5	Social acceptance	UWS	0	-	User-specified	Optimization (max)	Min=1 Max=10

5.1.3. Intervention Strategies

To address the above issues, three types of intervention options are proposed for this strategic planning as follows:

1. Addition of a new water resource along with two water treatment works (WTW);
2. Increased annual rehabilitation rate for pipes;
3. Addition of rainwater harvesting (RWH) and grey water recycling (GWR) schemes;

Based on the above individual intervention options, the following seven UWS intervention strategies (alternatives) against the 30 year planning horizon (2011-2040) are proposed:

- A0** Business as usual (BAU);
- A1** Addition of a new water resource along with two WTWs starting from 2020;
- A2** 1% additional annual pipe rehabilitation starting from 2015;
- A3** Addition of RWH and GWR systems at a local level by 25% of households starting from 2015;
- A4** Addition of RWH and GWR systems at a local level by 25% and 50% of households, respectively, starting from 2015;
- A5** Addition of RWH and GWR systems at a local level by 50% of households starting from 2015;
- A6** Addition of RWH and GWR systems at a local level by 25% of households and 0.5% additional rehabilitation annually starting from 2015;

The first strategy assumes business as usual (BAU), i.e. effectively ‘do nothing’ in the UWS over the planning horizon 2011-2040. In fact, the BAU assumes there is no intervention options are added to the UWS over the planning horizon when the specific rate of population growth (high or low) is envisaged. Therefore, the performance of the other six intervention strategies (A1-6) comprised of at least one intervention option are compared to each other plus the first strategy. Note that the intervention strategies numbered A2 to 6 start from 2015 while strategy A1 starts from 2020. Applying each of these intervention strategies is expected to have some specific impacts on the performance metrics of the UWS. These performance metrics specified for this analysis are described in the following.

5.1.4. Stakeholders preferences

Comparison of the intervention strategies with respect to the above performance metrics can be conducted based on either equal metric weights or some specific weighting schemes based on priorities of different groups/parties. For the sake of this analysis, three weighting schemes, including equal weights, Water Company and Consumer perspectives, are considered for ranking the intervention strategies (Table 6).

Table 6. Metric weighting schemes according to differing stakeholder preferences

	PERFORMANCE METRIC					
	M0. Reliability of Supply	M1. Total Costs	M2. GHG emissions	M3. Leakage	M4. CSO volume	M5. Social acceptance
W0. Equal weights	1	1	1	1	1	1
W1. Public	4	1	3	1	3	5
W2. Water company	5	3	2	4	1	4

5.2. Desktop DSS Application

The desktop DSS is used here to demonstrate the assessment of aforementioned intervention strategies with respect to the specified performance metrics for two differing scenarios of population growth. Therefore, a step-by-step procedure for setting up and running the DSS for the analysis of the problem is described below. Before running the DSS, the input data need to be specified and populated through the following three steps:

1. Problem definition;
2. Population of decision matrices;
3. Ranking of alternatives.

These steps are explained below in further details for the case study problem.

5.2.1. Problem definition

Using the GUI of the DSS software, the following data, according the information in section 3.2, is defined for the general data of case study problem:

- Name/description: Long-term planning of the a northern European city water supply system
- Planning horizon start year: 2011
- Planning horizon time steps: 30 time steps, each 1 year-long (i.e. end of planning horizon in year 2040)

5.2.2. Population of Decision matrix

Specification of Scenarios

The following specifications of the two scenarios of the case study problem described in Table 3 and Table 4 are added in the Scenario section of the DSS by clicking **Add** button as shown in Figure 5.2. Each scenario is defined in the DSS as follows:

1. Scenario **S0**.
 - ID: Low Growth
 - Description: Low Population Growth
 - Type: Water Demand Growth
 - Variable(s): The three variables with annual time series values listed in Table 3 are specified in this scenario.
2. Scenario **S1**.
 - ID: High Growth
 - Description: High Population Growth
 - Type: Water Demand Growth
 - Variable(s): The three variables with annual time series values listed in Table 4 are specified in this scenario

Note that as soon as a “Water Demand Growth” type is selected from dropdown box, the associated variables (in this case the four variables relating to annual demand growth) are automatically shown. Once a scenario has been added, it can be edited, cloned (a quick way to make a new scenario based on the data of one of the existing scenarios) or deleted by clicking on the relevant scenario in the list of existing scenarios and selecting the appropriate button on the Scenario portion of the Ribbon toolbar. Figure 5.3 shows the input data for both scenarios in the case study problem once they have been populated in the relevant forms.

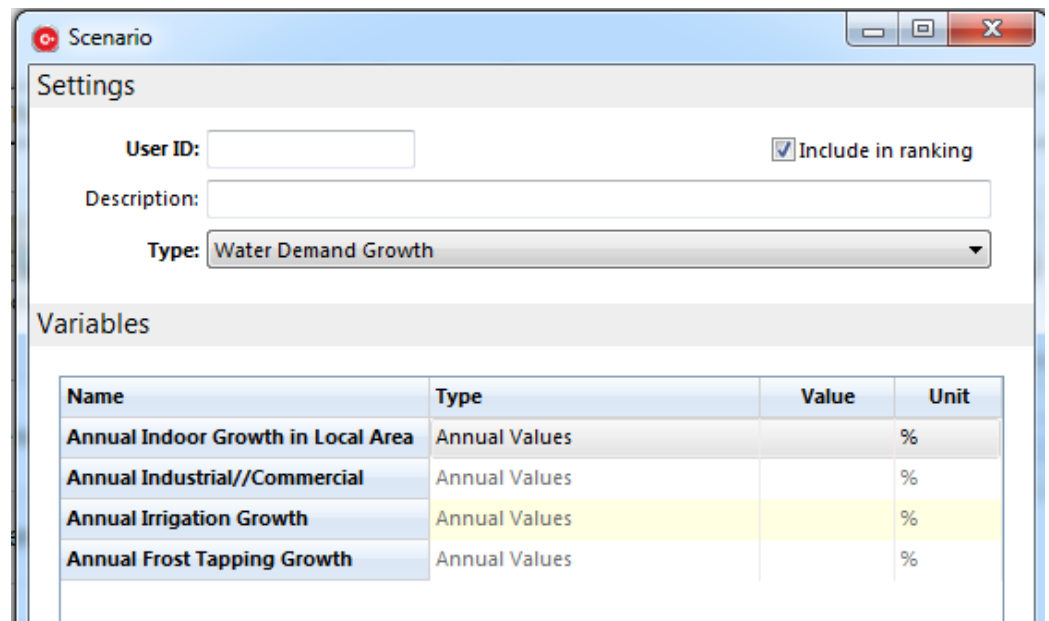


Figure 5.2 New scenario for the case study

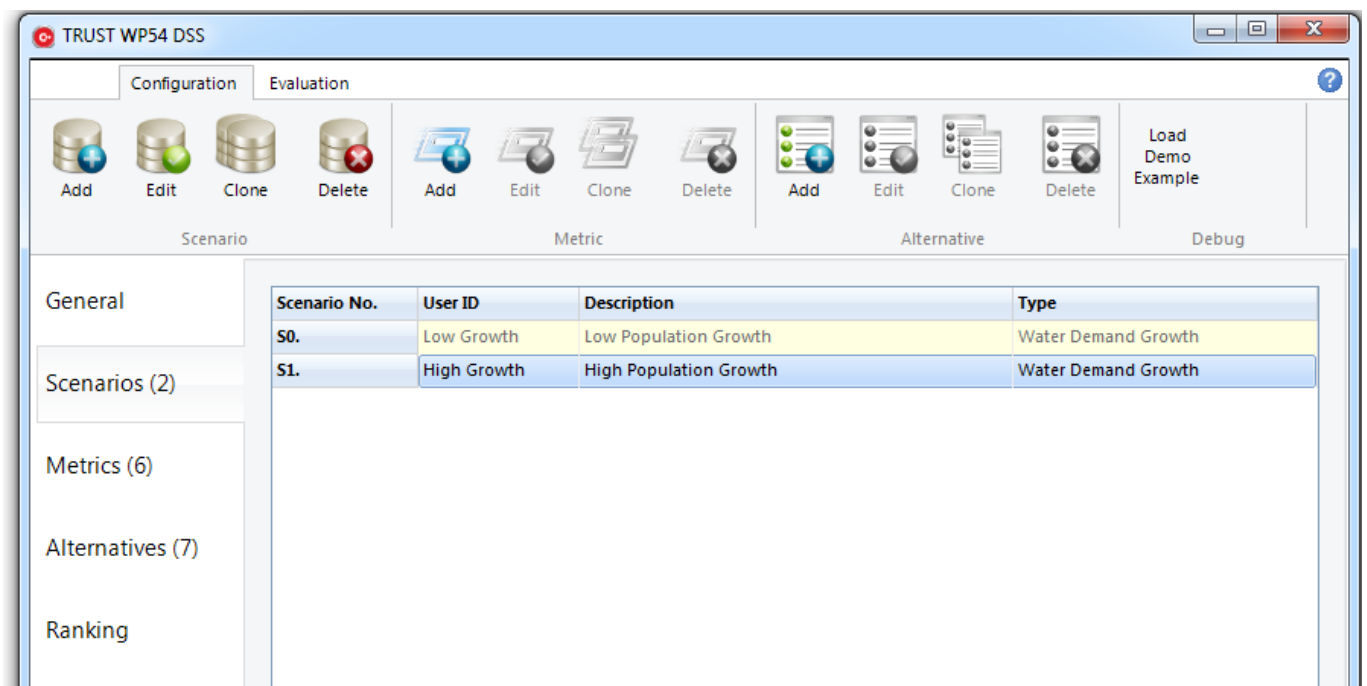
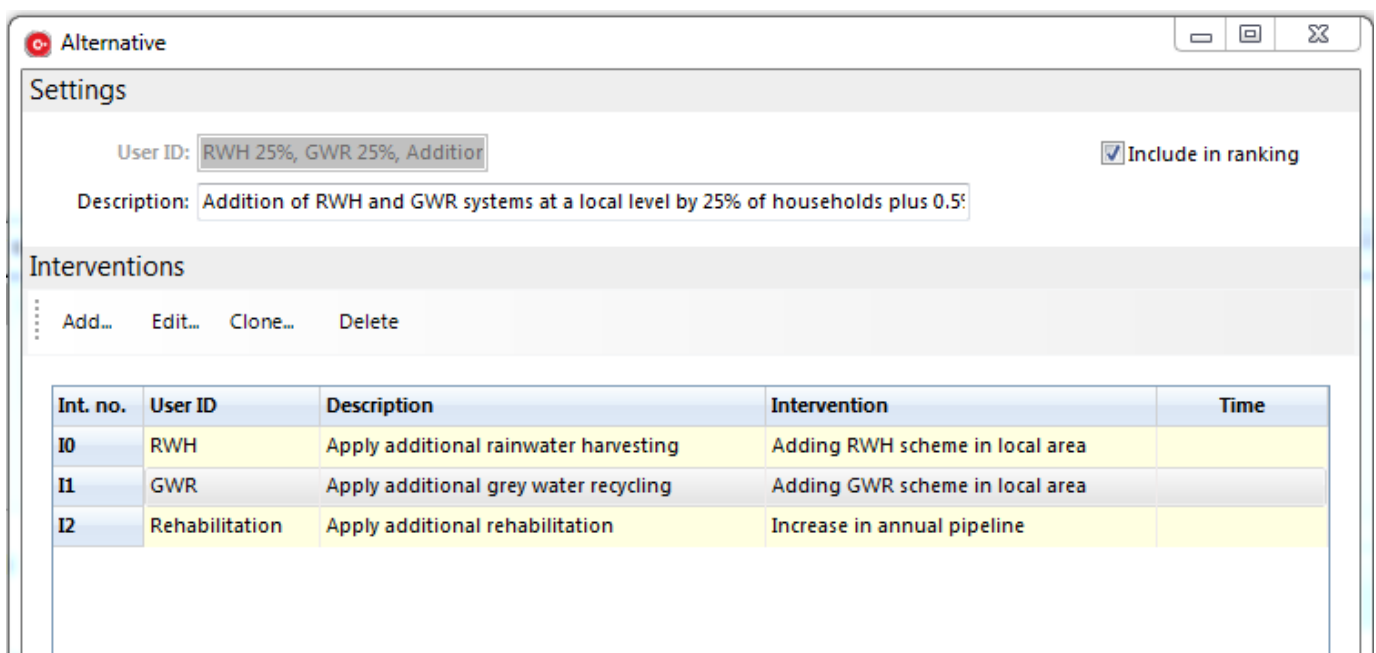


Figure 5.3 Populated input data for both scenarios of the case study problem in the DSS

Specification of Intervention Strategies

The third step is to define the intervention strategies as a set of individual interventions, each applied at pre-specified point in time over the planning horizon. The specifications of the seven intervention strategies as described in section 5.1.2 are added in the **Alternative** section of the DSS based on the data in Appendix C. A sample of populated individual intervention options (for Intervention Strategy A6) is shown in Figure 5.4. A sample of populated intervention strategy (for part of Intervention Strategy A1) is shown in Figure 5.5.



Alternative

Settings

User ID: Include in ranking

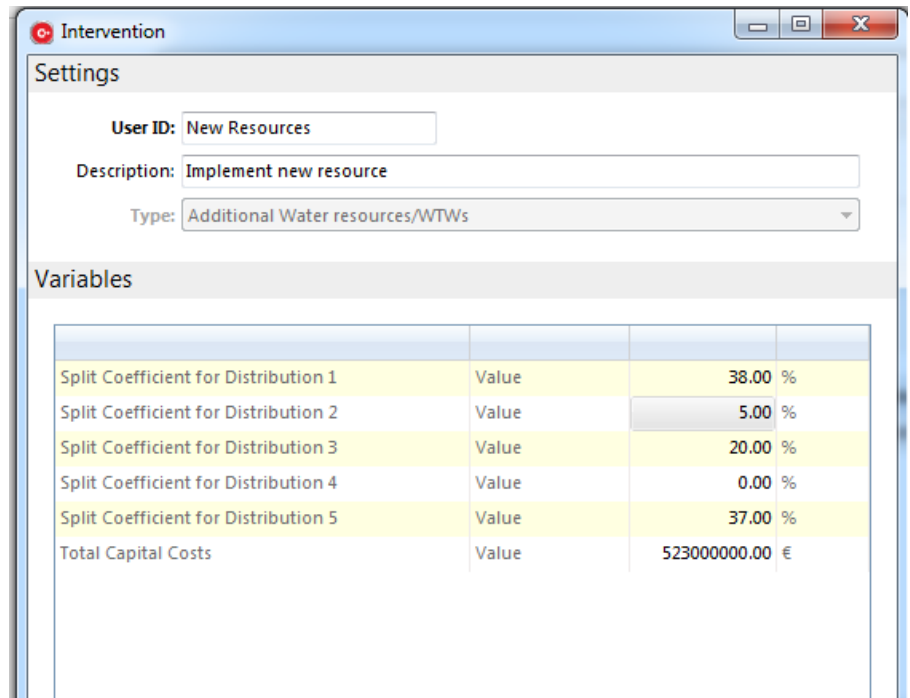
Description:

Interventions

... Add... Edit... Clone... Delete

Int. no.	User ID	Description	Intervention	Time
I0	RWH	Apply additional rainwater harvesting	Adding RWH scheme in local area	
I1	GWR	Apply additional grey water recycling	Adding GWR scheme in local area	
I2	Rehabilitation	Apply additional rehabilitation	Increase in annual pipeline	

Figure 5.4 An intervention strategy populated for the case study problem in the DSS



Settings

User ID:

Description:

Type:

Variables

Split Coefficient for Distribution 1	Value	38.00	%
Split Coefficient for Distribution 2	Value	5.00	%
Split Coefficient for Distribution 3	Value	20.00	%
Split Coefficient for Distribution 4	Value	0.00	%
Split Coefficient for Distribution 5	Value	37.00	%
Total Capital Costs	Value	523000000.00	€

Figure 5.5 An individual intervention option populated for the case study problem in the DSS

The completed list of seven intervention strategies for the case study problem will appear as shown in Figure 5.6.

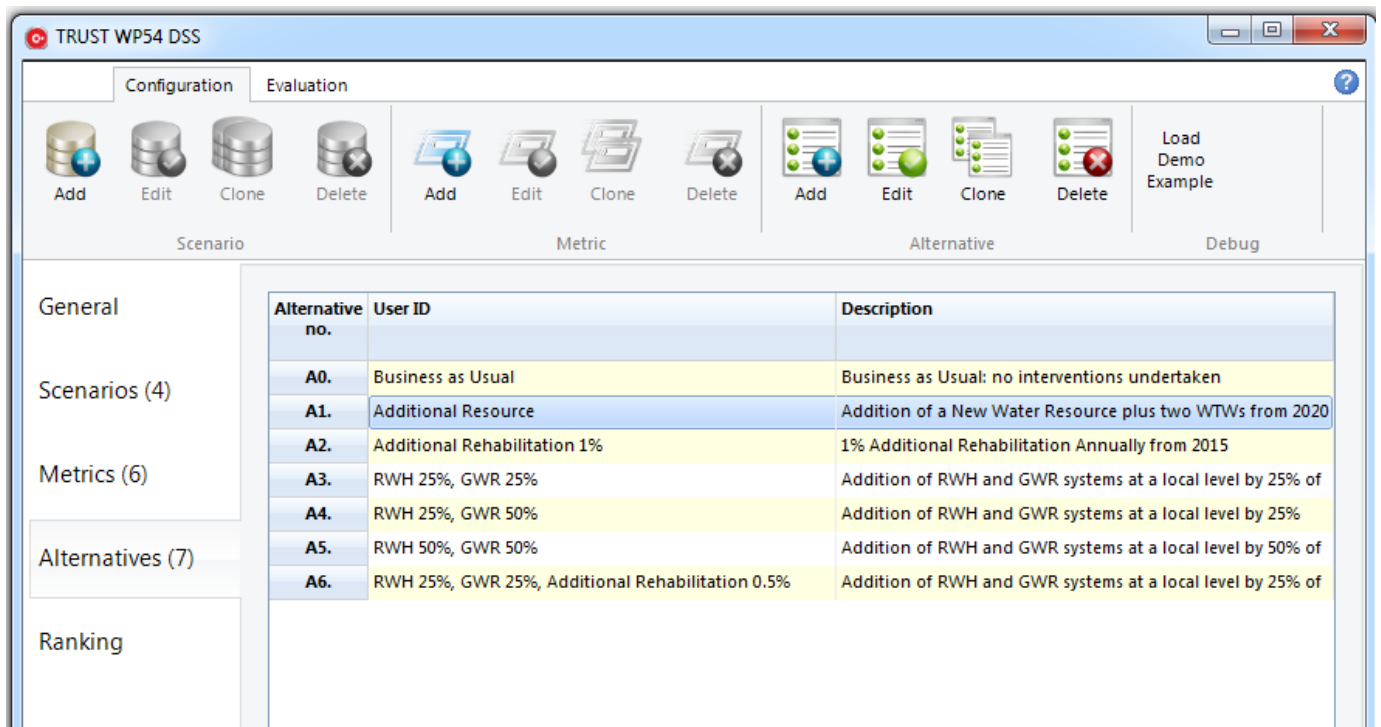
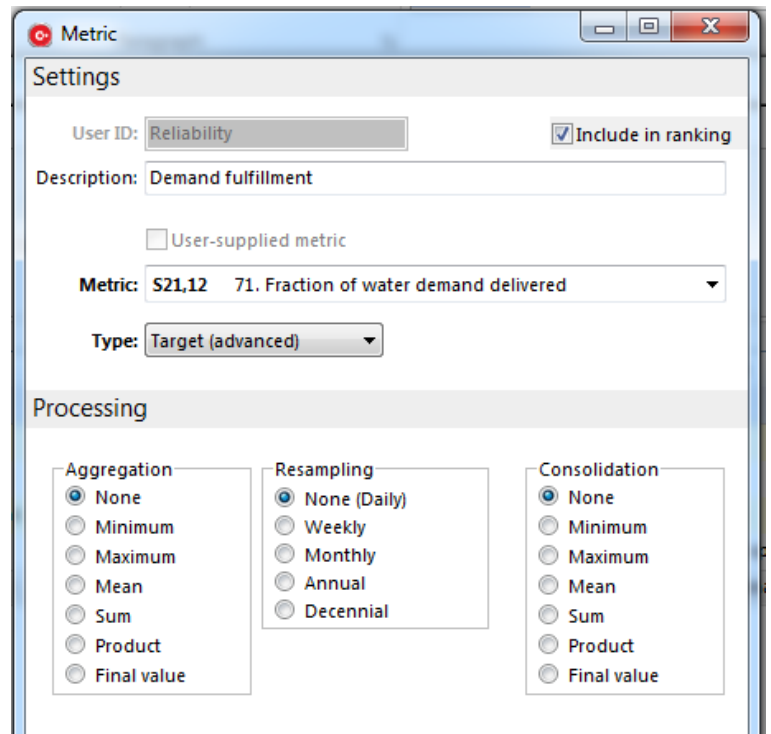


Figure 5.6 List of populated intervention strategies for the case study problem in the DSS

In the fourth step of inputting data for the case study, the performance metrics are defined. These are populated in the Add Metric form (Figure 5.7). In this, the user also needs to specify for each of the metrics the three parameters related to the processing (i.e. Aggregation type, resampling type and consolidation). These parameters are specified according to the information in Table 5. The populated table of performance metrics for the case study problem in the DSS is shown in Figure 5.8.



Settings

User ID: Reliability Include in ranking

Description: Demand fulfillment

User-supplied metric

Metric: S21,12 71. Fraction of water demand delivered

Type: Target (advanced)

Processing

<p>Aggregation</p> <p><input checked="" type="radio"/> None</p> <p><input type="radio"/> Minimum</p> <p><input type="radio"/> Maximum</p> <p><input type="radio"/> Mean</p> <p><input type="radio"/> Sum</p> <p><input type="radio"/> Product</p> <p><input type="radio"/> Final value</p>	<p>Resampling</p> <p><input checked="" type="radio"/> None (Daily)</p> <p><input type="radio"/> Weekly</p> <p><input type="radio"/> Monthly</p> <p><input type="radio"/> Annual</p> <p><input type="radio"/> Decennial</p>	<p>Consolidation</p> <p><input checked="" type="radio"/> None</p> <p><input type="radio"/> Minimum</p> <p><input type="radio"/> Maximum</p> <p><input type="radio"/> Mean</p> <p><input type="radio"/> Sum</p> <p><input type="radio"/> Product</p> <p><input type="radio"/> Final value</p>
---	---	---

Figure 5.7 A performance metric (reliability) populated for the case study problem

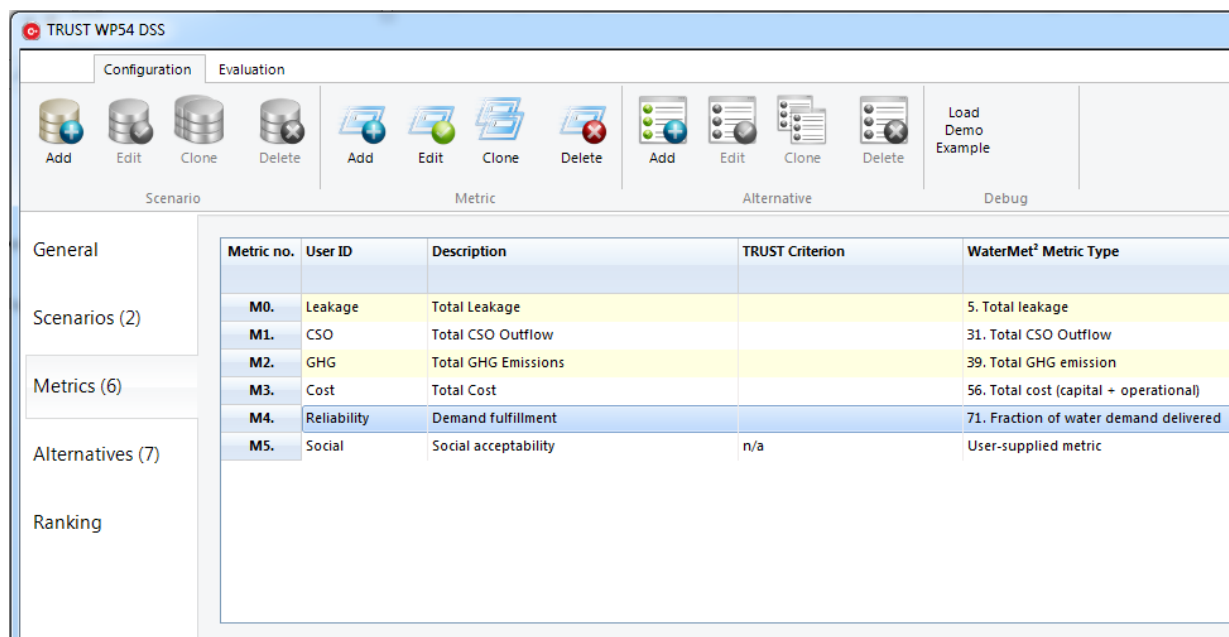


Figure 5.8 Populated performance metric table for the case study problem

After completing the four steps of the input data in the Configuration ribbon menu, the performance and then ranking of intervention strategies are assessed. Completion of the decision matrix is carried out in two distinct steps of automatic and manual population. The first step is to automatically calculate the metrics which can be quantified by WaterMet². This can be done by clicking **Populate Matrix** button. Other metrics which need to be quantified manually or which are qualitative are clearly recognised by their distinct pink colour in the Decision Matrix Table. In the case study problem, five out of six metrics are quantified automatically by WaterMet² and the only qualitative metric (M5) is quantified by relevant experts and the quantified values incorporated in the DSS for the purposes of ranking. Instead of using qualitative categories (linguistic terms) for metric M5, these are rated as scoring on a scale of acceptance ranging from 1 to 10, being: extremely low (1-2), low (3-4), medium (5-6), high (7-8) and extremely high (9-10). The finally quantified performance metrics for each intervention strategy in the case study problem (i.e. the final decision matrix) is obtained as shown in Figure 5.9.

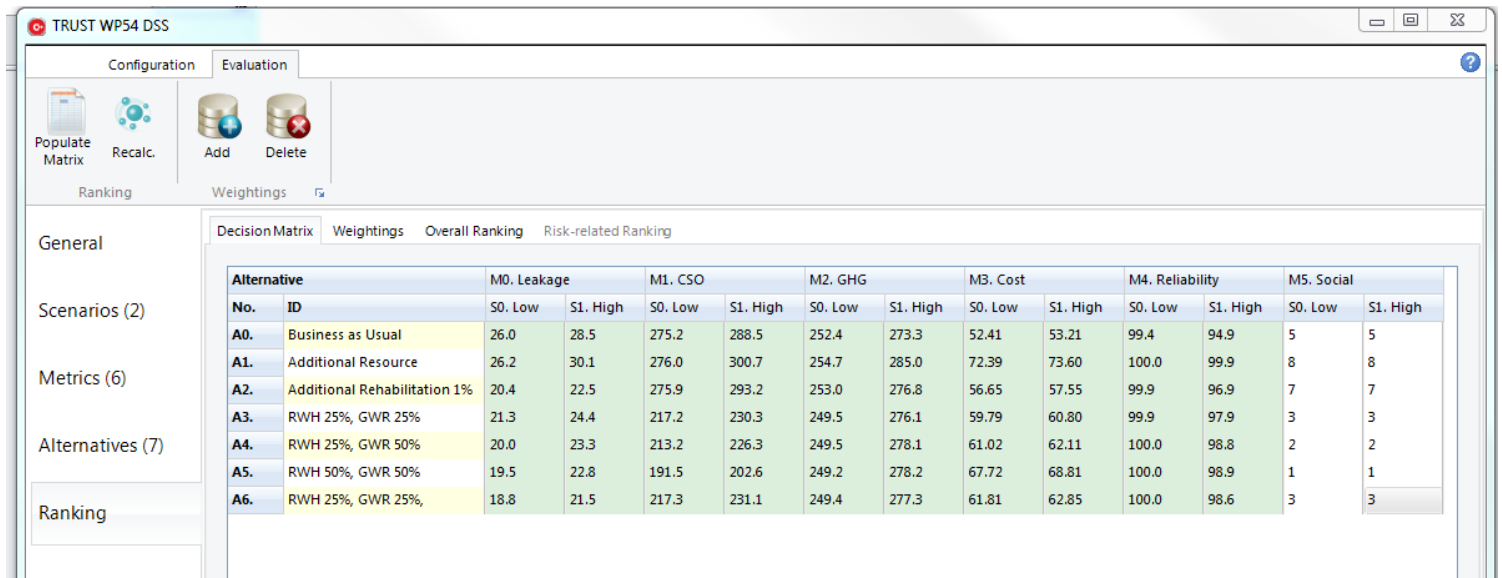


Figure 5.9 Quantified performance metrics for each intervention strategy in the case study problem

5.2.3. Ranking of alternatives

Before ranking can take place, the DSS needs to have any associated target/goals and preferences, described in the following sections, specified. The three sets of weighting schemes are populated in the **Weighting** tab of the **Ranking** section in the DSS (Figure 5.10). A new weighting scheme can be added by clicking Add button in the **Evaluation** ribbon menu. The list of the three weighting schemes populated for the case study problem in the DSS is shown in Figure 5.10.

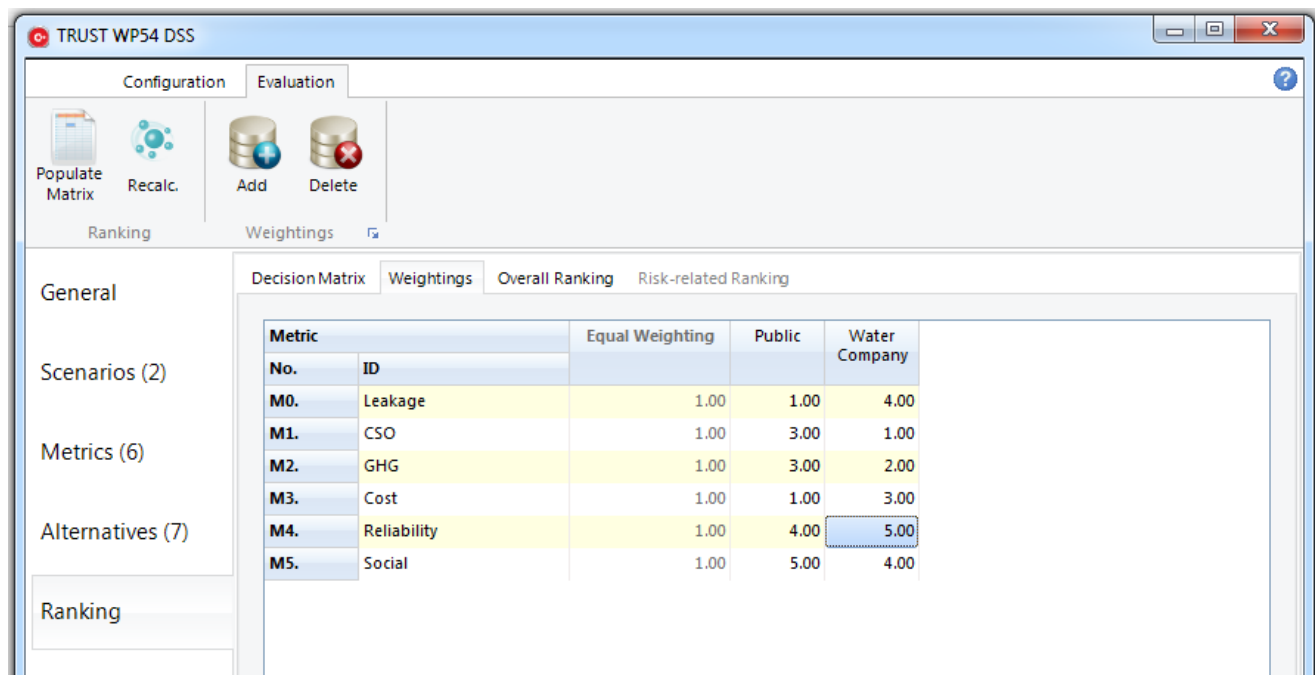
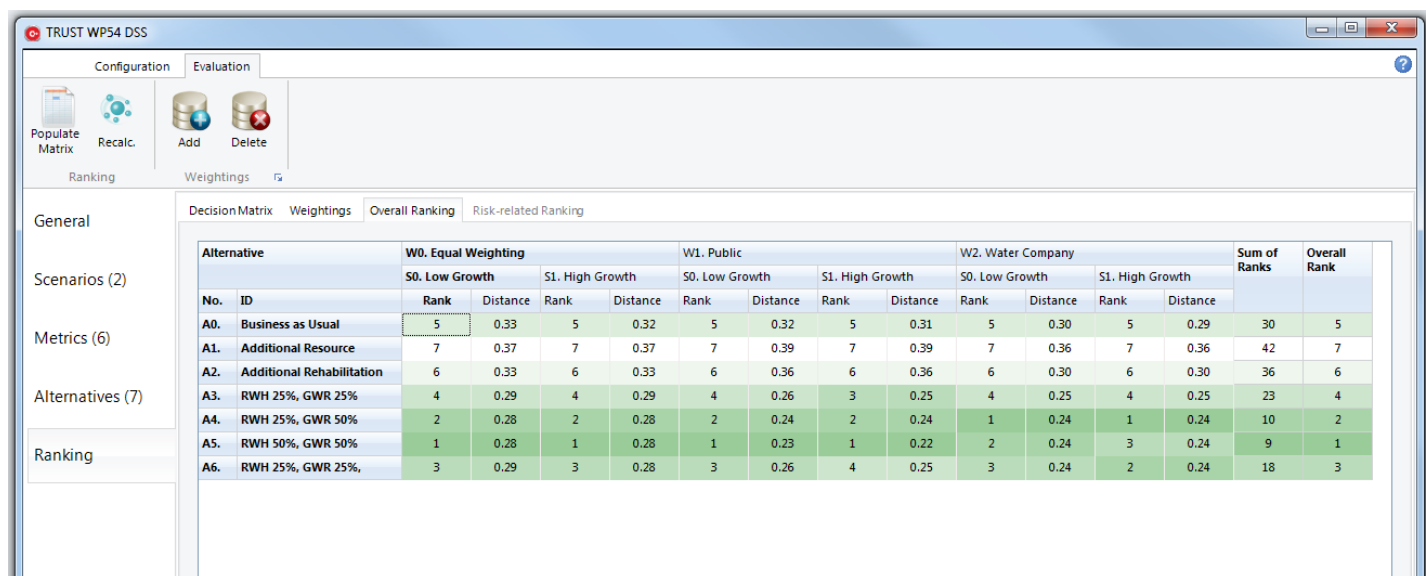


Figure 5.10 List of the three weighting schemes populated for the case study problem

Finally the ranking of the intervention strategies is obtained for all scenarios in the DSS by clicking the **Recalculate** Button in the **Evaluation** ribbon menu. . The final ranking is shown in Figure 5.11 for this case study. Here the ranking has been obtained using the Compromise Programming (CP) MCDA method (Zeleny 1973). A graded colour scale has been used to highlight the ranking of intervention strategies such that the highest ranked intervention strategies are distinguished by a darker shade of green.

Given the three weighting schemes and two scenarios, six groups of ranking for the intervention strategies are obtained are shown in Figure 5.11. The sum of the rankings of strategies is used to produce an overall ranking for each scenario. Ultimately, the sum of the rankings for all strategies for each of the different weighting scheme and scenario combinations is used to determine the final ranking of each alternative, as shown in the last column of the Table shown in Figure 5.11. As can be seen from this table, strategy A5, which has been constantly ranked high, is selected as the best rank in both scenarios in this example. Strategies A2 and A1 are ranked the lowest in both scenarios. Therefore, while strategy A5 is recommended as amongst the best strategies, strategies A2 and A1 are not recommended based on the results obtained from the numerical example. However, more analyses would be required to cover and test different criteria for these strategies.



The screenshot shows the TRUST WP54 DSS software interface. The main window displays a ranking table with the following data:

Alternative	No.	ID	W0. Equal Weighting				W1. Public				W2. Water Company				Sum of Ranks	Overall Rank
			S0. Low Growth		S1. High Growth		S0. Low Growth		S1. High Growth		S0. Low Growth		S1. High Growth			
			Rank	Distance	Rank	Distance	Rank	Distance	Rank	Distance	Rank	Distance	Rank	Distance		
A0.		Business as Usual	5	0.33	5	0.32	5	0.32	5	0.31	5	0.30	5	0.29	30	5
A1.		Additional Resource	7	0.37	7	0.37	7	0.39	7	0.39	7	0.36	7	0.36	42	7
A2.		Additional Rehabilitation	6	0.33	6	0.33	6	0.36	6	0.36	6	0.30	6	0.30	36	6
A3.		RWH 25%, GWR 25%	4	0.29	4	0.29	4	0.26	3	0.25	4	0.25	4	0.25	23	4
A4.		RWH 25%, GWR 50%	2	0.28	2	0.28	2	0.24	2	0.24	1	0.24	1	0.24	10	2
A5.		RWH 50%, GWR 50%	1	0.28	1	0.28	1	0.23	1	0.22	2	0.24	3	0.24	9	1
A6.		RWH 25%, GWR 25%	3	0.29	3	0.28	3	0.26	4	0.25	3	0.24	2	0.24	18	3

Figure 5.11 Ranking table of intervention strategies including overall ranking obtained for all scenarios in the case study problem

5.3. Web-based DSS Application

5.3.1. Problem definition

The files needed to run this case in the web-based DSS application are available in the Projects common folder: the user must log on to the software, go to Data Manager, and navigate to the Projects common folder, which is a top-level folder accessible to all users. The files are in the ‘WP54 Example Case’ sub-folder and include:

- A WaterMet² xml model file.
- 3 examples of a DSS analysis file, using the above WaterMet² model with different metric weights reflecting diverse viewpoints — ‘equal weights’, ‘public’ and ‘water company’.

The files should be copied to the user’s own folder before starting any analysis (see Section 4.2.1). The WaterMet² xml model file contains a full problem definition, including the evaluation of a range of 72 metrics for 7 alternatives in 2 scenarios.

In order to start a new DSS analysis using this WaterMet² model, create a new DSS file.

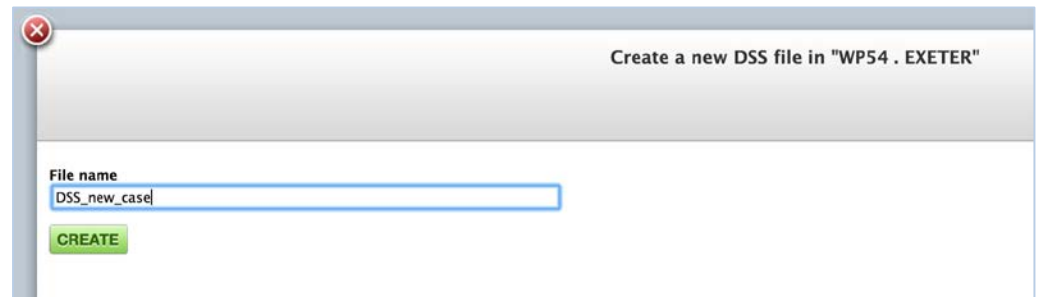


Figure 5.12 Create a new DSS file

In the application main screen, go to the WaterMet² model drawer and press select model.

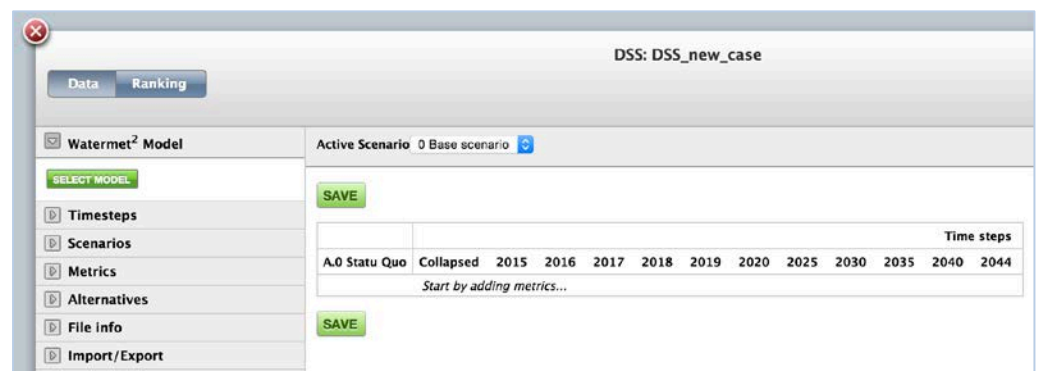


Figure 5.13 Frontpage of DSS new case

Navigate to the folder where the copy of the WaterMet² model file was placed and select it.



Figure 5.14 Form for selecting a WaterMet² file

The next step is to select the time steps in the appropriate drawer.

The model specifies 7 alternatives and 2 scenarios. They can all be imported by clicking on the **[import all]** options. Individual alternatives or scenarios may be examined by selecting them in the respective drawers (they can also be individually eventually removed from the analysis, using the Delete option). It is important to examine the scenarios' properties and edit the probability of occurrence, which is used for risk-based prioritization (see 5.3.3 below).

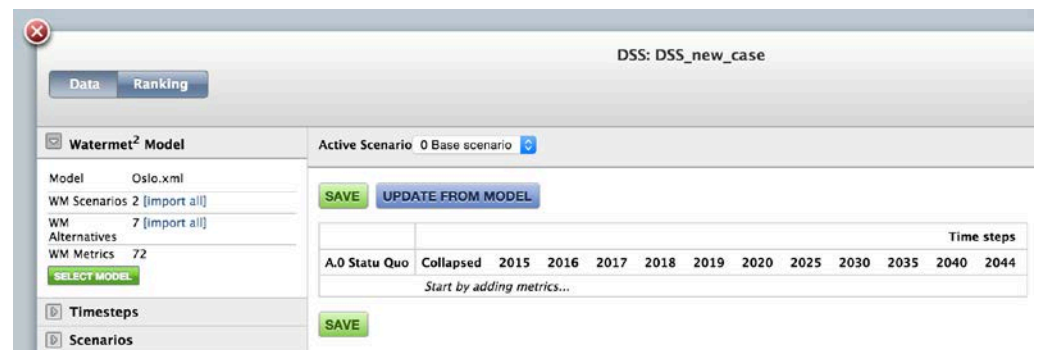


Figure 5.15 DSS form after opening a WaterMet² file

The next step is to select metrics. The case uses 5 metrics available from the WaterMet² model (31-Total CSO, 39-Total GHG emissions, 5-Total leakage, 56-Total cost, 71-Reliability), and a user-defined metric (00-Social Acceptance). In order to select the WaterMet² metrics, it is necessary to click **Add metric** in the **Metrics** drawer, then uncheck the **User-defined** option and select from the **WaterMet² Model Code** list that becomes available.

In order to create the 00-Social Acceptance user-defined metric, it is necessary simply to insert a code (00, in this case) and a name (Social Acceptance). The metrics configuration options shown below for the 6 metrics are illustrated for an equal weights viewpoint:

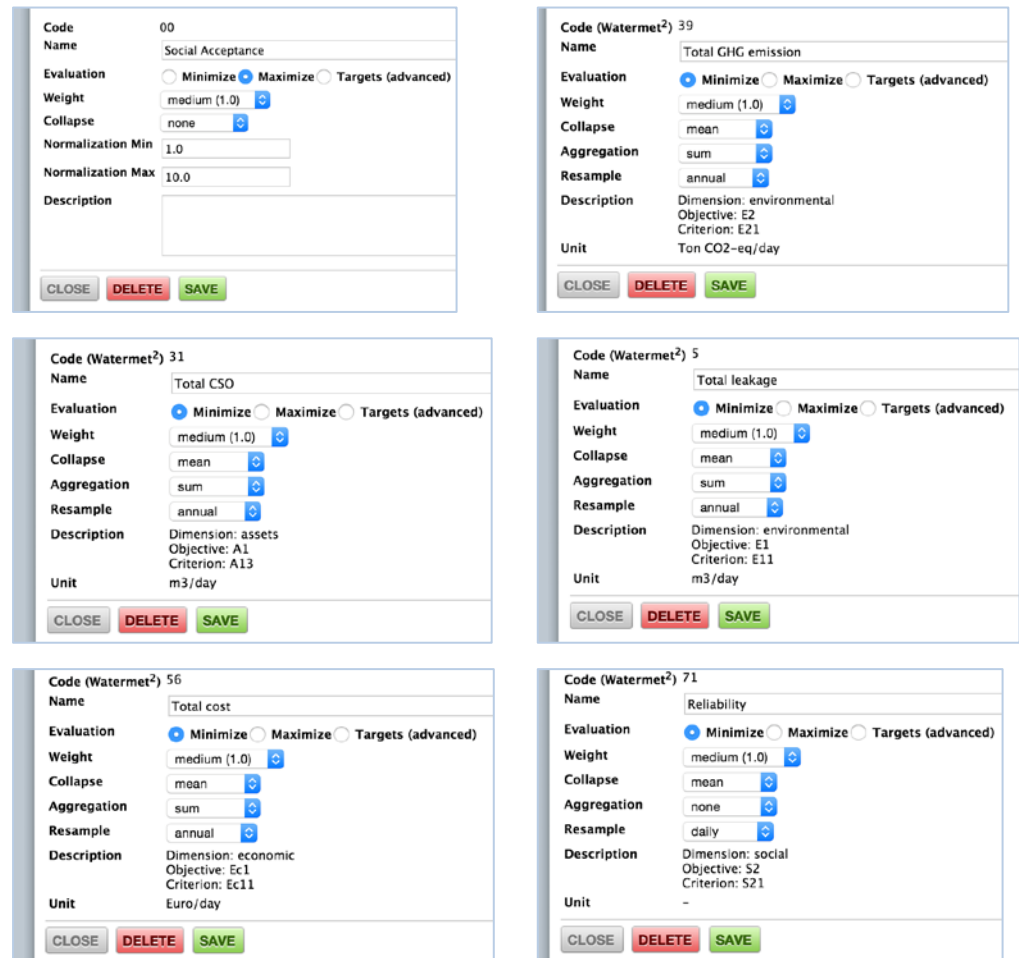


Figure 5.16 Selecting metrics in web-based DSS

5.3.2. Population of Decision matrix

After the selection of time steps, metrics, alternatives and scenarios has taken place, the decision matrix is laid out as shown below. The user-defined metric is directly editable by the user on the table. The WaterMet²-originated metrics will be populated by the model, by pressing the **Update from Model** button at the top of the table.

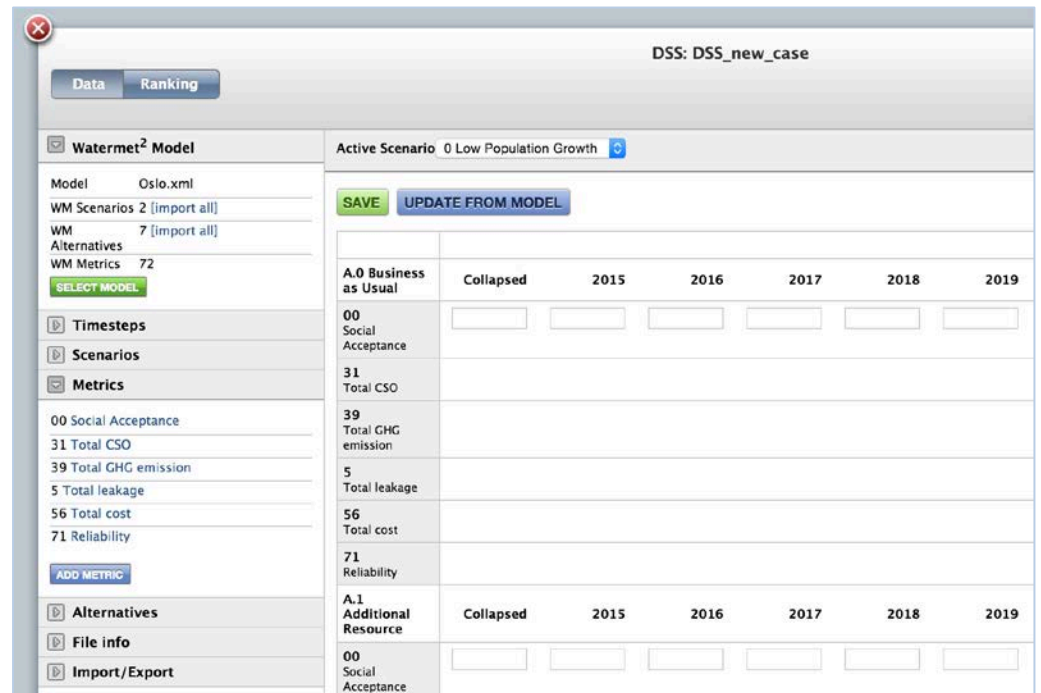


Figure 5.17 Population of decision matrices

The Active Scenario list at the top selects the scenario whose decision matrix is shown.

The MS Excel[®] import/export feature described in 4.2.3 (Exporting/importing the DSS matrix to/from MS Excel[®]) is a useful resource for mass editing user-defined as well as model-generated metrics values.

5.3.3. Ranking of alternatives

The ranking of alternatives may be examined by selecting the **Ranking** tab at the top left of the screen. Result tables (prioritization of alternatives) for each scenario are presented.

The last table displays a risk-based prioritization of alternatives for all the scenarios, considering the scenario probabilities that were specified in the scenario definition forms available in the **Scenario** drawer.

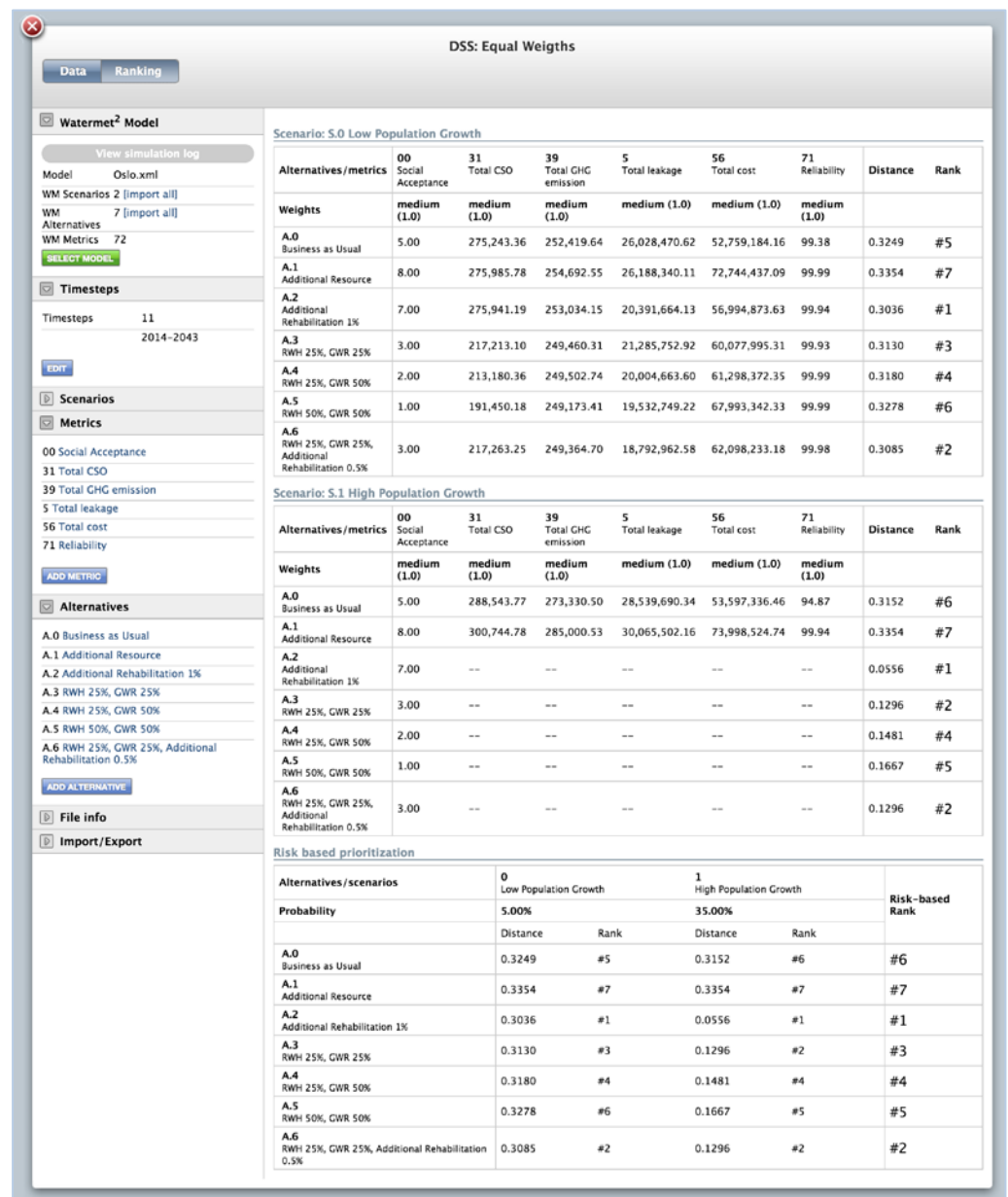


Figure 5.18 ranking of alternatives

In order to obtain a similar analysis for a different set of weights:

1. leave the DSS application and go to Data Manager;
2. duplicate the DSS file by clicking on its line on the Data Manager list (but away from the file name); the Duplicate As option appears at the top; create a duplicate with a different name;
3. open the new file in the DSS application, then proceed to change the metrics' weights.

6. SUMMARY AND CONCLUSIONS

A novel Decision Support System was developed to facilitate decision-making for the long-term city metabolism planning problem. This represents a new methodology for comparison and selection of alternative intervention strategies, within the framework of long-term transition paths, accommodating multiple decision criteria and able to deal with uncertain future scenarios and differing stakeholder perspectives.

Both the DSS methodology and software tool were described first in detail. Then, the effectiveness of the DSS was demonstrated on an idealized European city case study. The case study involved the assessment of seven alternative intervention strategies in an UWS over a 30 year planning horizon. The DSS employs the WaterMet² model which was used to calculate the six quantitative type metrics for the two scenarios of different future population growth. A further, qualitative metric quantified by experts outside the DSS was also included in the decision matrix to represent social acceptability of each intervention strategy. The DSS was then used to rank the intervention strategies using the Compromise Programming MCDA method for several different weighting schemes representing different stakeholder preferences. The most robust intervention strategy was then identified as the one that was ranked highly in all scenarios and for different stakeholder preferences.

The results obtained on the case study demonstrate that the DSS developed and presented here can be used to effectively and efficiently assist the planners in making better, more objective and strategic level decisions with respect to meeting the long-term goals and performance targets in their Urban Water system/City.

Based on the analyses conducted in this report, the following conclusions can be drawn:

- The newly introduced implementations of the DSS are useful software tools which can be efficiently used by urban decision makers and water authorities for the strategic-level planning of future Urban Water Systems. The levels of detail required for modelling and simulating alternative intervention strategies are less complex than similar, physically-based models and the previously developed conceptually based models; hence the UWS itself and the relevant intervention strategies can be easily modelled.
- The DSS tools can easily handle a variety of key performance indicators and assessment criteria including both quantitative and qualitative metrics which are derived from the sustainability-based framework in water systems (Alegre *et al.*, 2012). Most quantitative UWS performance criteria can be calculated by the DSS through the integrated metabolism-based WaterMet² model (Behzadian *et al.*, 2014b). The performance indicators calculated by WaterMet² concentrate particularly on estimating the sustainability type criteria - in addition to more conventional performance criteria.
- The final output of the DSS is the rankings of a variety of alternative intervention strategies under a number of scenarios and for differing stakeholder perspectives.

Whilst this system may not be able to identify the detailed interventions to be implemented for the top ranked strategies, the DSS is able to inform 'big picture'-style planning and to identify the most promising transition path(s) as an input to the next (tactical/operational) level of planning.

- The DSS enables the decision makers to measure the long-term impact of intervention alternatives on an integrated UWS including water supply, wastewater and stormwater subsystems simultaneously. This also enables planners to identify both shortcomings of the existing system state and intervention options for improving the system-wide performance.

Both versions of the DSS are user-friendly and can be trained with minimal training resources, compared to some other similar models/DSS. The time required for an expert to analyse a new UWS depends largely on modelling the UWS in the WaterMet² metabolism model (Behzadian *et al.*, 2015). After building a new WaterMet² model for the UWS, the population of different intervention strategies, performance indicators and multiple scenarios is a rapid process within the DSS environment. The run time for calculating performance indicators in the DSS depends on the number of intervention strategies and performance criteria and scenarios defined but in general varies between 5 and 30 minutes for both versions of the tool.

7. REFERENCES

- Alegre, H., Cabrera jr., E., Hein, A. and Brattebø, H. (2012), *Framework for Sustainability Assessment of UWCS and development of a self-assessment tool*. TRUST Project Report, Deliverable D31.1 (<https://www.trust-i.net/>).
- Bach, P. M., Rauch, W., Mikkelsen, P. S., McCarthy, D. T. and Deletic, A. (2014). A critical review of integrated urban water modelling—Urban drainage and beyond. *Environmental Modelling & Software*, **54**, pp88-107.
- Behzadian, K. and Kapelan, Z., (2013), *Oslo Case Study Report*, TRUST Internal Report, Milestone MS26 (<https://www.trust-i.net/>).
- Behzadian, K., Kapelan, Z., Rozos, E. and Makropoulos, C., (2013a). *WaterMet² conceptual model report*, TRUST Project Report, Deliverable D33.1 (<https://www.trust-i.net/>).
- Behzadian, K., Kapelan, Z., Venkatesh, G., Brattebø, H., Sægrov, S., Rozos, E., Makropoulos, C., Ugarelli, R., Milina, J. and Hem, L. (2013b). Urban water system metabolism assessment using WaterMet² model, *12th International Conference on Computing and Control*, Italy, vol. 15.
- Behzadian, K., Kapelan, Z., Venkatesh, G., Brattebø, H. and Sægrov, S. (2014a). WaterMet²: analysis tool for sustainability performance of urban water systems, *Drink. Water Eng. Sci. Discuss. (DWESD)*, **7**, pp1–26, doi:10.5194/dwesd-7-1-2014.
- Behzadian, K. and Kapelan, Z. (2015). Modelling Metabolism Based Performance of Urban Water System Using WaterMet², *Resources, Conservation and Recycling*, Elsevier; in press.
- Behzadian, K., Kapelan, Z., Venkatesh, G., Brattebø, H., Sægrov, S., Rozos, E. and Makropoulos, C. (2014b) *Quantitative UWS Performance Model: WaterMet²*, TRUST Project Report, Deliverable D33.2 (<https://www.trust-i.net/>).
- Brown, R.R., Keath, N. and Wong, T.H.F., (2009). Urban water management in cities: historical, current and future regimes. *Water Sci. Technol.* **59**(5), pp847-855.
- Butler, D. and Memon, F.A., (2006). *Water Demand Management*. IWA publishing, London.
- Hardy, M.J., Kuczera, G., Coombes, P.J., (2005). Integrated urban water cycle management: the urban cycle model. *Water Sci. Technol.* **52**(9), pp1-9.
- ISO (2009). 31000: *Risk management – Principles and Guidelines*. International Standards Organization, Geneva, Switzerland.

- Mackay, R. and Last, E. (2010), SWITCH city water balance: a scoping model for integrated urban water management. *Reviews in Environmental Science and Bio/Technology* **9**(4) pp291-296.
- Makropoulos, C.K., Natsis, K., Liu, S., Mittas, K. and Butler, D. (2008), Decision support for sustainable option selection in integrated urban water management. *Environmental Modelling & Software* **23**(12), pp1448-1460.
- Mitchell, V.G., Mein, R.G. and McMahon, T.A., (2001), Modelling the urban water cycle. *Environmental Modelling & Software*, **16**(7), pp615-629.
- Mitchell, V.G. and Diaper, C. (2010), *UVQ User Manual: (urban water balance and contaminant balance analysis tool)*, Version 1.2, CMIT Report No. 2005-282. CSIRO.
- Morley, M.S., Kapelan, Z. and Savić, D.A. (2012), *Integrated Decision Support Framework*. TRUST Project Report, Deliverable D54.1 (<https://www.trust-i.net/>).
- Morley, M.S., Behzadian, K. and Kapelan, Z. (2015), *WP54: TRUST DSS Memo*. TRUST Project Report, Deliverable D54.2 (<https://www.trust-i.net/>).
- Nair, S., George, B., Malano, H. M., Arora, M. and Nawarathna, B. (2014), Water–energy–greenhouse gas nexus of urban water systems: Review of concepts, state-of-art and methods. *Resour., Conserv. and Recycl.*, **89**, pp1-10.
- Saaty, T.L. (1980). *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*, ISBN 0-07-054371-2, McGraw-Hill, New York, U.S.A. 287pp.
- Ugarelli, R., Ceu Almeida, M., Behzadian, K., Liserra, T., Smeets, P., Kapelan, Z. and Sægrov, S. (2014). Sustainability Risk Based Assessment of Integrated Urban Water System, *11th International Conference on Hydroinformatics*, HIC 2014, New York City,
- Ugarelli, R., Ceu Almeida, M., Liserra, T. and Smeets, P. (2014). Metabolism Risk-Controlled Model. TRUST Project Internal Report, Deliverable D32.1 (<https://www.trust-i.net/>).
- Venkatesh, G., Sægrov, S., and Brattebø, H. (2014) Dynamic metabolism modelling of urban water services–Demonstrating effectiveness as a decision-support tool for Oslo, Norway. *Water res.*, **61**, pp19-33.
- Vitorino D., Morley, M.S., Behzadian, K., Kapelan, Z. and Ugarelli, R. (2013), *WP54 DSS/Aware-P baseform software integration*, TRUST Internal Report (<https://www.trust-i.net/>).
- Warner, W.S., (2006). *Understanding greywater treatment*. In: Butler, D. and Memon, F.A. (eds.), *Water Demand Management*. IWA Publishing, London.

- Willuweit, L., and O'Sullivan, J. J. (2013). A decision support tool for sustainable planning of urban water systems: Presenting the Dynamic Urban Water Simulation Model. *Water research*, **47**(20), pp7206-7220.
- Zeleny, M., (1973). Compromise Programming. In: *Multiple Criteria Decision Making*, Cochrane and M. Zeleny (Editors), University of South Carolina Press: Columbia, South Carolina.

8. APPENDICES

8.1. Appendix A: List of performance metrics supported by WaterMet²

Table A 1 Pls for a number of UWS components

NO	WATER RESOURCES	WATER SUPPLY CONDUITS	WTWS	TRUNK MAINS	SERVICE RESERVOIRS	DISTRIBUTION MAINS
1	Inflow	Inflow	Inflow	Inflow	Inflow	Inflow
2	Volume	Leakage	Loss	Leakage	Volume	Leakage
3	Loss	Delivered Outflow	Delivered Outflow	Delivered Outflow	Loss	Delivered Outflow
4	Delivered Outflow	Undelivered Outflow (Lack of Inflow)	Undelivered Outflow (Lack of Inflow)	Undelivered Outflow (Lack of Inflow)	Delivered Outflow	Undelivered Outflow (Lack of Inflow)
5	Undelivered Outflow	Undelivered Outflow (Exceeding Capacity)	Undelivered Outflow (Exceeding Capacity)	Undelivered Outflow (Exceeding Capacity)	Undelivered Outflow	Undelivered Outflow (Exceeding Capacity)
6	Overflow	Total Energy	Overflow	Total Energy	Overflow	Total Energy
7	Total Energy	Electricity Energy	Total Energy	Electricity Energy	Total Energy	Electricity Energy
8	Electricity Energy	Fossil Fuel Energy	Electricity Energy	Fossil Fuel Energy	Electricity Energy	Fossil Fuel Energy
9	Fossil Fuel Energy	Embodied Energy	Fossil Fuel Energy	Embodied Energy	Fossil Fuel Energy	Embodied Energy
10	Embodied Energy	Total GHG Emission	Embodied Energy	Total GHG Emission	Embodied Energy	Total GHG Emission
11	Total GHG Emission	Electricity GHG Emission	Total GHG Emission	Electricity GHG Emission	Total GHG Emission	Electricity GHG Emission
12	Electricity GHG Emission	Fossil Fuel GHG Emission	Electricity GHG Emission	Fossil Fuel GHG Emission	Electricity GHG Emission	Fossil Fuel GHG Emission
13	Fossil Fuel GHG Emission	Embodied GHG Emission	Fossil Fuel GHG Emission	Embodied GHG Emission	Fossil Fuel GHG Emission	Embodied GHG Emission
14	Embodied GHG Emission	Acidification	Embodied GHG Emission	Acidification	Embodied GHG Emission	Acidification
15	Acidification	Eutrophication	Acidification	Eutrophication	Acidification	Eutrophication
16	Eutrophication	Total Cost	Eutrophication	Total Cost	Eutrophication	Total Cost
17	Total Cost	Capital Cost	Total Cost	Capital Cost	Total Cost	Capital Cost
18	Capital Cost	Operational Cost	Capital Cost	Operational Cost	Capital Cost	Operational Cost
19	Operational Cost	Energy Generation	Operational Cost		Operational Cost	
20			Sludge Generation			

Table A 2 PIs for a number of UWS components (subcatchments, sewer systems and WWTWs)

NO	SUBCATCHMENTS	SEWER SYSTEMS	WWTWS
1	Total Water Demand	Storm water Inflow	Inflow
2	Total Delivered Water Demand	Excess Storm water	Volume
3	Total Potable water Demand	Storm water Volume	Loss
4	Total Delivered Potable water Demand	Sanitary Sewage Inflow	Treated Outflow
5	Total Undelivered Potable water Demand	Excess Wastewater	Untreated Outflow (CSO)
6	Total Delivered Rainwater Harvesting	Wastewater Volume	Total Energy
7	Total Collected Rainwater Harvesting	STO	Electricity Energy
8	Total Delivered Grey Water Recycling	CSO	Fossil Fuel Energy
9	Total Collected Grey Water Recycling	Total Energy	Embodied Energy
10	Potable Domestic Water Demand	Electricity Energy	Total GHG Emission
11	Potable Industrial Water Demand	Fossil Fuel Energy	Electricity GHG Emission
12	Potable Irrigation Water Demand	Total GHG Emission	Fossil Fuel GHG Emission
13	Potable Frost Tapping Water Demand	Electricity GHG Emission	Embodied GHG Emission
14	Potable Unregistered Water Demand	Fossil Fuel GHG Emission	Acidification
15	Delivered RHW for Domestic Water Demand	Acidification	Eutrophication
16	Delivered RHW for Industrial Water Demand	Eutrophication	Total Cost
17	Delivered RHW for Irrigation Water Demand	Total Cost	Capital Cost
18	Delivered GWR for Domestic Water Demand	Capital Cost	Operational Cost
19	Delivered GWR for Industrial Water Demand	Operational Cost	Contaminant Load
20	Delivered GWR for Irrigation Water Demand	Contaminant Load	Inflow Contaminant Load
21	% of Water Demand Delivered	Inflow Sewer System Contaminant Load	Outflow Contaminant Load
22	Total Energy	Inflow Storm Drainage System Contaminant Load	Overflow Contaminant Load
23	Electricity Energy	Excess wastewater Contaminant Load	Sludge Generation
24	Fossil Fuel Energy	Excess Storm water Contaminant Load	Resource Recovery
25	Embodied Energy	Outflow Sewer System Contaminant Load	Biogas generated
26	Total GHG Emission	Outflow Storm Drainage System Contaminant Load	ammonium nitrate generated
27	Electricity GHG Emission	CSO Contaminant Load	Single superphosphate generated
28	Fossil Fuel GHG Emission	STO Contaminant Load	Urea generated
29	Embodied GHG Emission		
30	Acidification		
31	Capital Cost		
32	Operational Cost		

Table A 3. List of performance metrics in WaterMet² classified in accordance with dimensions of sustainability in water systems

DIMENSION	OBJECTIVES	ASSESSMENT CRITERIA	PIS SUPPORTED BY WATERMET ²	
			NAME	UNIT
Social	S1) Access to urban water services	S11) Service coverage	Not supported by the WaterMet ² model	-
	S2) Effectively satisfy the current users' needs and expectations	S21) Quality of service	Water supply	
			Delivered/undelivered total water demand*	m ³ /day
			Delivered/undelivered potable water demand*	m ³ /day
			Potable domestic/industrial/irrigation water demand*	m ³ /day
			Percentage of water demand delivered*	%
			Wastewater system and stormwater	
			Stormwater inflow**	m ³ /day
			Excess stormwater**	m ³ /day
			Sanitary sewage inflow**	m ³ /day
			Excess sanitary sewage**	m ³ /day
		S22) Safety and health	Not supported by the WaterMet ² model	-
	S3) Acceptance and awareness of UWCS	S31) Affordability	Partially supported by WaterMet ² by calculating operational cost of water supply and wastewater systems	-
Environment	En1) Efficient use of water, energy and materials	En11) Efficiency in the use of water (including final uses)	Total leakage	m ³ /day
			Collected rainwater harvesting (RWH)/ grey water recycling (GWR)**	m ³ /day
			Delivered RWH/GWR**	m ³ /day
			Delivered RWH/GWR for domestic/industrial/irrigation water demand**	m ³ /day
			Local area/subcatchment RWH/GWR tank volume	m ³

DIMENSION	OBJECTIVES	ASSESSMENT CRITERIA	PIS SUPPORTED BY WATERMET ²	
			NAME	UNIT
Economic	En2) Minimisation of other environmental impacts	En12) Efficiency in the use of energy	Electricity/fossil fuel/embodied energy for each component modelled in WaterMet ²	KWh/day
			Energy generation recovered from biogas, anaerobic digestion, turbine-generators in WWTWs	KWh/day
		En13) Efficiency in the use of materials	Chemicals used for treatments in WTWs/WWTWs	Kg/day
			Ammonium nitrate recovery in WWTWs	Kg/day
			Sludge generation in WTWs/WWTWs and RWH/GWR systems in local area/subcatchment	Kg/day
		En21) Environmental efficiency (resource exploitation and life cycle emissions to water, air and soil)	Greenhouse gas emission resulted from electricity/fossil fuel/embodied energy for each component modelled in WaterMet ²	Kg CO ₂ -eq./day
			Acidification for each component modelled in WaterMet ²	Kg SO ₂ -eq./day
			Eutrophication for each component modelled in WaterMet ²	Kg PO ₄ -eq./day
			Contaminant load (e.g. Tot-C, Tot-N, Tot-P) of sewer system inflow **	Kg/day
			Contaminant load of drainage system inflow **	Kg/day
			Contaminant load of excess wastewater/stormwater **	Kg/day
			Contaminant load of outflow from sewer/storm drainage system **	Kg/day
		En2) Minimisation of other environmental impacts	Combined sewer overflow (CSO) from sewer system/WWTWs	m ³ /day
	Treated outflow from WWTWs		m ³ /day	
	Contaminant load in CSO from sewer system/WWTWs		Kg/day	
	Contaminant load in storm tank overflow (STO)		Kg/day	
	En2) Minimisation of other environmental impacts	Contaminant load in treated wastewater from WWTWs	Kg/day	
Contaminant load in treated wastewater from WWTWs		Kg/day		
En1) Ensure economic	En11) Cost recovery and reinvestment in UWCS (incl.	Capital cost for each component modelled in WaterMet ²	Euro/day	

DIMENSION	OBJECTIVES	ASSESSMENT CRITERIA	PIS SUPPORTED BY WATERMET ²	
			NAME	UNIT
Governance	sustainability of the UWCS	cost financing)		
		Ec12) Economic efficiency	Operational cost for each component modelled in WaterMet ²	Euro/day
		Ec13) Leverage (degree of indebtedness)	Not supported by the WaterMet ² model	-
		Ec14) Willingness to pay		
	G1) Public participation	G11) Participation initiatives	Not supported by the WaterMet ² model	-
	G2) Transparency and accountability	G21) Availability of information and public disclosure		
		G22) Availability of mechanisms of accountability		
	G3) Clearness, steadiness and measurability of the UWCS policies	G31) Clearness, steadiness, ambitiousness and measurability of policies		
	G4) Alignment of city, corporate and water resources planning	G41) Degree of alignment of city, corporate and water resources planning		
	Assets	A1) Infrastructure reliability, adequacy and resilience	A11) Adequacy of the rehabilitation rate	Flux (mass) of Pipeline rehabilitation in distribution mains
Flux (length) of Pipeline rehabilitation in distribution mains				Km/day
Flux (number) of Pipeline rehabilitation in distribution mains				No of pipe/day
Flux (mass) of Pipeline rehabilitation in stormwater/wastewater system				Kg/day
Flux (length) of Pipeline rehabilitation in stormwater/wastewater system				Km/day
Flux (number) of Pipeline rehabilitation in stormwater/wastewater system				No of pipe/day
A12) Reliability and failures			Not supported by the WaterMet ² model	-
A13) Adequate infrastructural capacity			Overflow for each component ^{***}	m ³ /day
A14) Adaptability to changes (e.g. climate change	Delivered/Undelivered outflow ^{****}	m ³ /day		

DIMENSION	OBJECTIVES	ASSESSMENT CRITERIA	PIS SUPPORTED BY WATERMET ²	
			NAME	UNIT
		Adaptation)		
	A2) Human capital	A21) Adequacy of training, capacity building and knowledge transfer	Not supported by the WaterMet ² model	-
	A3) Information and knowledge management	A31) Quality of the information and of the knowledge management system		

*PI applies for each water supply component (i.e. water resources, water supply conduits, WTWs, trunk mains, service reservoirs and distribution mains), subcatchment and urban water system (UWS).

**PI applies for each subcatchment and UWS.

***PI applies for water resources, WTWs, service reservoirs.

****PI applies for water resources, water supply conduits, WTWs, trunk mains, service reservoirs, distribution mains.

8.2. Appendix B: WaterMet² intervention options and associated variables

SUBSYSTEM	INDIVIDUAL INTERVENTION OPTION	VARIABLES IN WATERMET ² MODEL
Water Resources	Modifying storage capacity, abstraction licences/adding water resources	Storage capacity of water resources (m ³)
	Upgrading the efficiency of water conservation in water resources	Water loss in water resources (%)
	Upgrading water abstraction technology	Fixed annual O&M cost in water resources (Euro/year)
		Unit electricity consumption in water resources (KWh/m ³)
		Unit fossil fuel consumption in water resources (L/m ³)
	Modifying/adding pumping capacity	Unit electricity consumption in water resources (KWh/m ³)
Unit fossil fuel consumption in water resources (L/m ³)		
Water Supply Conduits (Aqueducts)/ Trunk mains/ distribution mains	Increasing transmission capacity/pipeline diameters	Transmission capacity of conduits/trunk/distribution mains (m ³ /day)
	Upgrading technology of water transmission in pipelines	Fixed annual O&M cost (Euro/year)
		Unit electricity consumption in component (KWh/m ³)
		Unit fossil fuel consumption in component (L/m ³)
	Modifying/adding pumping capacity	Unit electricity consumption in component (KWh/m ³)
		Unit Fossil fuel consumption in component (L/m ³)
	Increasing rate of annual pipeline rehabilitation	Leakage reduction (%)
Modifying/adding active leakage control	Leakage reduction (%)	
	Fixed annual O&M cost (Euro/year)	

SUBSYSTEM	INDIVIDUAL INTERVENTION OPTION	VARIABLES IN WATERMET ² MODEL
	Upgrading pipeline rehabilitation technology	Cost of pipeline rehabilitation for each technology (Euro/m)
		GHG emission of pipeline rehabilitation for each technology (Euro/m)
Service Reservoir	Modifying/adding water storage capacity in service reservoirs	Storage capacity of service reservoirs (m ³)
	Upgrading the efficiency of water conservation in service reservoirs	Water loss in service reservoirs (%)
	Upgrading water treatment technology and service reservoirs	Average chemicals costs in service reservoirs (Euro/m ³)
		Amount and type of chemicals used in service reservoirs (kg/m ³)
Upgrading operational technology	Fixed annual O&M cost in service reservoirs (Euro/year)	
WTWs	Modifying water treatment capacity /adding, new WTWs	Treatment capacity in WTWs (m ³ /day)
	Upgrading the efficiency of water conservation in WTWs	Water loss in WTWs (%)
	Upgrading operational technology of water treatment in physical/chemical processes	Physical/chemical fixed annual O&M cost in WTWs (Euro/year)
		Physical/chemical unit electricity consumption in WTWs (KWh/m ³)
		Physical/chemical unit fossil fuel consumption in WTWs (L/m ³)
	Modifying/adding pumping capacity	Physical/chemical fixed annual O&M cost in WTWs (Euro/year)
Physical/chemical unit electricity consumption in WTWs (KWh/m ³)		

SUBSYSTEM	INDIVIDUAL INTERVENTION OPTION	VARIABLES IN WATERMET ² MODEL
		Physical/chemical Unit fossil fuel consumption in WTWs (L/m ³)
	Upgrading water treatment Water demand technology	Sludge generation in WTWs (kg/m ³)
		Average chemicals costs in WTWs (Euro/m ³)
		Amount and type of chemicals used in WTWs (kg/m ³)
		Chemical fixed annual O&M cost in WTWs (Euro/year)
	Use of water efficient appliances and fittings in households/industry	Indoor water demand (L/day/capita)
	Use of energy efficient appliances and fittings in households/industry	Unit electricity consumption for appliances and fittings in household (KWh/m ³)
	Use of solar energy for appliances and fittings in households/industry	Unit electricity consumption for appliances and fittings in household (KWh/m ³)
	Modifying/increasing water metering coverage	Indoor water demand (L/day/capita)
	Applying/upgrading water recycling technology in industry	Industrial water demand (m ³ /day)
	Upgrading irrigation/garden watering technology	Irrigation water demand (m ³ /day)
	Applying native and drought resistant plant	Irrigation water demand (m ³ /day)
	Upgrading frost tapping technology	Frost tapping water demand (m ³ /day)
	Separation of drinking water distribution system from non-drinking water demands	Indoor water demand (L/day/capita)
		Industrial water demand (m ³ /day)
Irrigation water demand (m ³ /day)		

SUBSYSTEM	INDIVIDUAL INTERVENTION OPTION	VARIABLES IN WATERMET ² MODEL
		Fixed annual O&M cost of distribution mains (Euro/year)
		Unit electricity consumption of distribution mains (KWh/m ³)
		Unit fossil fuel consumption of distribution mains (L/m ³)
	Increasing awareness of water consumption	Indoor water demand (L/day/capita)
		Irrigation water demand (m ³ /day)
	Increasing water service prices	Indoor water demand (L/day/capita)
		Industrial water demand (m ³ /day)
		Irrigation water demand (m ³ /day)
Water resources recovery	Modifying/adding RWH system capacity	Storage capacity of RWH tank at local area/subcatchment (m ³)
	Upgrading water consumption of RWH system	Allocating RWH system for various water demand profiles (e.g. appliances and fittings and other demand categories such as irrigation and industrial)
	Upgrading operational technology in RWH system	Fixed annual O&M cost in RWH tank at local area/subcatchment (Euro/year)
		Unit electricity consumption in RWH tank at local area/subcatchment (KWh/m ³) Unit fossil fuel consumption in RWH tank at local area/subcatchment (L/m ³)
	Upgrading treatment technology in RWH system	Contaminant removal efficiency in RWH tank at local area/subcatchment (%)
Upgrading water sources in RWH system	At local area, adding new water sources for RWH system (e.g. runoff collection from roof, pavement & road)	

SUBSYSTEM	INDIVIDUAL INTERVENTION OPTION	VARIABLES IN WATERMET ² MODEL
		At subcatchment level, adding new water sources for RHW system (e.g. runoff collection from its own subcatchment or upstream subcatchments)
	Modifying/adding GWR system	Storage capacity of GWR tank at local area/subcatchment (m ³)
	Upgrading water consumption of GWR system	Allocating (treated) grey water of GWR system for various water demand consumptions (e.g. appliances and fittings and other demand categories such as irrigation and industrial)
	Upgrading operational technology in GWR system	Fixed annual O&M cost in GWR tank at local area/subcatchment (Euro/year)
		Unit electricity consumption in GWR tank at local area/subcatchment (KWh/m ³)
	Unit fossil fuel consumption in GWR tank at local area/subcatchment (L/m ³)	
	Upgrading treatment technology in GWR system	Contaminant removal efficiency in GWR tank at local area/subcatchment (%)
	Upgrading water sources in GWR system	At local area, allocation of collecting runoff for GWR system from water demand profiles (e.g. appliances and fittings and other demand categories such as irrigation and industrial)
	Modifying/adding centralised water recycling/reuse system	Storage capacity of centralised water recycling/reuse tank (m ³)
	Upgrading water consumption of centralised water recycling/reuse system	Allocating recycled water for various water demand consumptions (e.g. appliances and fittings and other demand categories such as irrigation and industrial)
Upgrading operational technology in centralised water recycling/reuse system	Fixed annual O&M cost in centralised water recycling tank (Euro/year)	
	Unit electricity consumption in centralised water recycling tank (KWh/m ³)	

SUBSYSTEM	INDIVIDUAL INTERVENTION OPTION	VARIABLES IN WATERMET ² MODEL
		Unit fossil fuel consumption in centralised water recycling tank (L/m ³)
	Upgrading sludge handling in WTWs	Sludge generation in WTWs (kg/m ³)
		Average chemicals costs in WTWs (Euro/m ³)
		Amount and type of chemicals used in WTWs (kg/m ³)
		Chemical fixed annual O&M cost in WTWs (Euro/year)
	Upgrading sludge handling in WWTWs	Contaminant removal efficiency in WWTWs (%)
		Average chemicals costs in WWTWs (Euro/m ³)
		Amount and type of chemicals used in WWTWs (kg/m ³)
		Fixed annual O&M cost in WWTWs (Euro/year)
	Upgrading resource recovery in WWTWs	Ammonium nitrate recovery in WWTWs (kg/m ³)
		Heat generated from biogas in WWTWs (KWh/m ³)
		Energy generated from biogas, anaerobic digestion, turbine-generator in WWTWs (KWh/m ³)
	Stormwater/Wastewater systems	Implementation of SUDS in urban stormwater drainage system
Pavement & Road area proportion of local area (%)		
Roof area proportion of local area (%)		
Runoff coefficient of local area (0-1)		
Infiltration coefficient of local area (0-1)		

SUBSYSTEM	INDIVIDUAL INTERVENTION OPTION	VARIABLES IN WATERMET ² MODEL
		Storage capacity of SUDS in local area (m ³)
	Modifying/adding sewer system capacity/pipeline diameters	Daily treatment capacity in stormwater/wastewater pipeline (m ³ /day)
		Storage capacity in stormwater/wastewater pipeline (m ³)
	Modifying/adding storage tank for sewer system	Storage capacity in stormwater/wastewater pipeline (m ³)
	Modifying/adding combined sewer overflow capacity	CSO structure capacity in combined sewer system(m ³ /day)
	Modifying/adding storm tank overflow capacity in stormwater drainage system	STO structure capacity in stormwater drainage system (m ³ /day)
	Upgrading operational technology of sewer system	Fixed annual O&M cost in sewer system (Euro/year)
		Unit electricity consumption in sewer system (KWh/m ³)
		Unit fossil fuel consumption in sewer system (L/m ³)
	Modifying/adding pumping capacity	Unit electricity consumption in sewer system (KWh/m ³)
Unit fossil fuel consumption in sewer system (L/m ³)		
Separating combined sewer systems	Definition of combined/separate sewer system for each subcatchment	
WWTWs	Modifying/adding wastewater treatment capacity	Daily treatment capacity in WWTWs (m ³ /day)
		Storage capacity in WWTWs (m ³)
	Upgrading operational technology of wastewater treatment	Fixed annual O&M cost in WWTWs (Euro/year)
		Unit electricity consumption in WWTWs (KWh/m ³)
		Unit fossil fuel consumption in WWTWs (L/m ³)
	Upgrading wastewater treatment	Contaminant removal efficiency in WWTWs (%)

SUBSYSTEM	INDIVIDUAL INTERVENTION OPTION	VARIABLES IN WATERMET ² MODEL
	technology and resource recovery	Average chemicals costs in WWTWs (Euro/m ³)
		Amount and type of chemicals used in WWTWs (kg/m ³)
	Modifying/adding energy generation by biogas	Unit electricity consumption in WWTWs (KWh/m ³)
		Unit fossil fuel consumption in WWTWs (L/m ³)

8.3. Appendix C: Specifications of the intervention strategies specified in the numerical example

INTERVENTION STRATEGY ID	INTERVENTION STRATEGY DESCRIPTION (NAME)	INDIVIDUAL INTERVENTION 1	INDIVIDUAL INTERVENTION 2	INDIVIDUAL INTERVENTION 3
1	Business as usual	None	None	None
2	Addition of a new water resource along with two WTWs starting from 2020	<p>Description: New water resource/WTWs</p> <p>Occurrence type: one-off</p> <p>First occurrence: 2020</p> <p>Location: water resources/WTWs</p> <p>Variables:</p> <p>ID=1</p> <p>Name= Split percentage for distribution mains</p> <p>Units=%</p> <p>Component ID= 1</p> <p>Magnitude= 38</p> <p>ID =2</p> <p>Name= Split percentage for distribution mains</p> <p>Units=%</p> <p>Component ID= 2</p> <p>Magnitude= 5</p> <p>ID =3</p> <p>Name= Split percentage for distribution mains</p>		

INTERVENTION STRATEGY ID	INTERVENTION STRATEGY DESCRIPTION (NAME)	INDIVIDUAL INTERVENTION 1	INDIVIDUAL INTERVENTION 2	INDIVIDUAL INTERVENTION 3
		Units=% Component ID= 3 Magnitude= 20 ID =4 Name= Split percentage for distribution mains Units=% Component ID= 5 Magnitude= 37 ID =5 Name= Total Capital Costs Units= Euros Magnitude= 523×10 ⁶		
3	1% additional rehabilitation annually starting from 2015	Description: Increase in annual pipeline rehabilitation rate Occurrence type: recurring First occurrence: 2015 Frequency: once a year Time period: 25 years Location: Distribution mains Variables: ID =1 Name= Leakage Rate Component ID= subcatchment 1		

INTERVENTION STRATEGY ID	INTERVENTION STRATEGY DESCRIPTION (NAME)	INDIVIDUAL INTERVENTION 1	INDIVIDUAL INTERVENTION 2	INDIVIDUAL INTERVENTION 3
		Magnitude= 1 %		
4	addition of RWH and GWR systems at a local level by 25% of households starting from 2015	<p>Description: Adding RWH scheme in local area Occurrence type: One-off First occurrence: 2015 Location: local area Variables:</p> <p>ID =1 Name= Storage capacity Component ID= subcatchment 1 and local area 1 Units= m³ Magnitude= 240,000</p> <p>ID =2 Name= Capital cost Component ID= subcatchment 1 and local area 1 Units= Euros Magnitude= 127,200,000</p> <p>ID =3 Name= O&M cost Component ID= subcatchment 1 and local area 1 Units= Euros/year Magnitude = 5,760,000</p>	<p>Description: Adding GWR scheme in local area Occurrence type: One-off First occurrence: 2015 Location: local area Variables:</p> <p>ID =1 Name= Storage capacity Component ID= subcatchment 1 and local area 1 Units= m³ Magnitude= 19,500</p> <p>ID =2 Name= Capital cost Component ID= subcatchment 1 and local area 1 Units= Euros Magnitude= 29,500,000</p> <p>ID =3 Name= O&M cost Component ID= subcatchment 1 and local area 1</p>	

INTERVENTION STRATEGY ID	INTERVENTION STRATEGY DESCRIPTION (NAME)	INDIVIDUAL INTERVENTION 1	INDIVIDUAL INTERVENTION 2	INDIVIDUAL INTERVENTION 3
		<p>ID =4 Name= Allocation of green water from RWH tank for Toilet consumption Component ID= subcatchment 1 and local area 1 Units=- Magnitude =True</p> <p>ID =5 Name= Allocation of green water from RWH tank for industrial consumption in subcatchment 1 and local area 1 Magnitude =True</p> <p>ID =6 Name= Allocation of green water from RWH tank for irrigation consumption Component ID= subcatchment 1 and local area 1 Units=- Magnitude =True</p>	<p>Units= Euros/year Magnitude = 750,000</p> <p>ID =4 Name= Allocation of green water from GWR tank for Toilet consumption Component ID= subcatchment 1 and local area 1 Units=- Magnitude =True</p> <p>ID =5 Name= Allocation of green water from GWR tank for industrial consumption Component ID= subcatchment 1 and local area 1 Units=- Magnitude =True</p> <p>ID =6 Name= Allocation of green water from GWR tank for irrigation consumption Component ID= subcatchment 1 and local area 1</p>	

INTERVENTION STRATEGY ID	INTERVENTION STRATEGY DESCRIPTION (NAME)	INDIVIDUAL INTERVENTION 1	INDIVIDUAL INTERVENTION 2	INDIVIDUAL INTERVENTION 3
			Units=- Magnitude =True	
5	addition of RWH and GWR systems at a local level by 25% and 50% of households, respectively, starting from 2015	<p>Description: Adding RWH scheme in local area Occurrence type: One-off First occurrence: 2015 Location: local area Variables:</p> <p>ID =1 Name= Storage capacity Component ID= subcatchment 1 and local area 1 Units= m³ Magnitude= 240,000</p> <p>ID =2 Name= Capital cost Component ID= subcatchment 1 and local area 1 Units= Euros Magnitude= 127,200,000</p> <p>ID =3 Name= O&M cost Component ID= subcatchment 1 and local area 1 Units= Euros/year Magnitude = 5,760,000</p>	<p>Description: Adding GWR scheme in local area Occurrence type: One-off First occurrence: 2015 Location: local area Variables:</p> <p>ID =1 Name= Storage capacity Component ID= subcatchment 1 and local area 1 Units= m³ Magnitude= 39,000</p> <p>ID =2 Name= Capital cost Component ID= subcatchment 1 and local area 1 Units= Euros Magnitude= 59,000,000</p> <p>ID =3 Name= O&M cost Component ID= subcatchment 1 and local area 1</p>	

INTERVENTION STRATEGY ID	INTERVENTION STRATEGY DESCRIPTION (NAME)	INDIVIDUAL INTERVENTION 1	INDIVIDUAL INTERVENTION 2	INDIVIDUAL INTERVENTION 3
		<p>ID =4 Name= Allocation of green water from RWH tank for Toilet consumption Component ID= subcatchment 1 and local area 1 Units=- Magnitude =True</p> <p>ID =5 Name= Allocation of green water from RWH tank for industrial consumption Component ID= subcatchment 1 and local area 1 Units=- Magnitude =True</p> <p>ID =6 Name= Allocation of green water from RWH tank for irrigation consumption Component ID= subcatchment 1 and local area 1 Units=- Magnitude =True</p>	<p>Units= Euros/year Magnitude = 1,500,000</p> <p>ID =4 Name= Allocation of green water from GWR tank for Toilet consumption Component ID= subcatchment 1 and local area 1 Units=- Magnitude =True</p> <p>ID =5 Name= Allocation of green water from GWR tank for industrial consumption Component ID= subcatchment 1 and local area 1 Units=- Magnitude =True</p> <p>ID =6 Name= Allocation of green water from GWR tank for irrigation consumption Component ID= subcatchment 1 and local</p>	

INTERVENTION STRATEGY ID	INTERVENTION STRATEGY DESCRIPTION (NAME)	INDIVIDUAL INTERVENTION 1	INDIVIDUAL INTERVENTION 2	INDIVIDUAL INTERVENTION 3
			area 1 Units=- Magnitude =True	
6	addition of RWH and GWR systems at a local level by 50% of households starting from 2015	Description: Adding RWH scheme in local area Occurrence type: One-off First occurrence: 2015 Location: local area Variables: ID =1 Name= Storage capacity Component ID= subcatchment 1 and local area 1 Units= m ³ Magnitude= 480,000 ID =2 Name= Capital cost Component ID= subcatchment 1 and local area 1 Units= Euros Magnitude= 254,400,000 ID =3 Name= O&M cost Component ID= subcatchment 1 and local area 1 Units= Euros/year	Description: Adding GWR scheme in local area Occurrence type: One-off First occurrence: 2015 Location: local area Variables: ID =1 Name= Storage capacity Component ID= subcatchment 1 and local area 1 Units= m ³ Magnitude= 39,000 ID =2 Name= Capital cost Component ID= subcatchment 1 and local area 1 Units= Euros Magnitude= 59,000,000 ID =3 Name= O&M cost Component ID= subcatchment 1 and local	

INTERVENTION STRATEGY ID	INTERVENTION STRATEGY DESCRIPTION (NAME)	INDIVIDUAL INTERVENTION 1	INDIVIDUAL INTERVENTION 2	INDIVIDUAL INTERVENTION 3
		<p>Magnitude = 11,520,000</p> <p>ID =4</p> <p>Name= Allocation of green water from RWH tank for Toilet consumption</p> <p>Component ID= subcatchment 1 and local area 1</p> <p>Units=-</p> <p>Magnitude =True</p> <p>ID =5</p> <p>Name= Allocation of green water from RWH tank for industrial consumption</p> <p>Component ID= subcatchment 1 and local area 1</p> <p>Units=-</p> <p>Magnitude =True</p> <p>ID =6</p> <p>Name= Allocation of green water from RWH tank for irrigation consumption in subcatchment 1 and local area 1</p> <p>Units=-</p> <p>Magnitude =True</p>	<p>area 1</p> <p>Units= Euros/year</p> <p>Magnitude = 1,500,000</p> <p>ID =4</p> <p>Name= Allocation of green water from GWR tank for Toilet consumption</p> <p>Component ID= subcatchment 1 and local area 1</p> <p>Magnitude =True</p> <p>ID =5</p> <p>Name= Allocation of green water from GWR tank for industrial consumption</p> <p>Component ID= subcatchment 1 and local area 1</p> <p>Units=-</p> <p>Magnitude =True</p> <p>ID =6</p> <p>Name= Allocation of green water from GWR tank for irrigation consumption in subcatchment 1 and local area 1</p> <p>Units=-</p>	

INTERVENTION STRATEGY ID	INTERVENTION STRATEGY DESCRIPTION (NAME)	INDIVIDUAL INTERVENTION 1	INDIVIDUAL INTERVENTION 2	INDIVIDUAL INTERVENTION 3
			Magnitude = True	
7	addition of RWH and GWR systems at a local level by 25% of households and 0.5% additional rehabilitation annually starting from 2015	<p>Description: Adding RWH scheme in local area Occurrence type: One-off First occurrence: 2015 Location: local area Variables:</p> <p>ID =1 Name= Storage capacity Component ID= subcatchment 1 and local area 1 Units= m³ Magnitude= 240,000</p> <p>ID =2 Name= Capital cost Component ID= subcatchment 1 and local area 1 Units= Euros Magnitude= 127,200,000</p> <p>ID =3 Name= O&M cost Component ID= subcatchment 1 and local area 1 Units= Euros/year Magnitude = 5,760,000</p> <p>ID =4</p>	<p>Description: Adding GWR scheme in local area Occurrence type: One-off First occurrence: 2015 Location: local area Variables:</p> <p>ID =1 Name= Storage capacity Component ID= subcatchment 1 and local area 1 Units= m³ Magnitude= 19,500</p> <p>ID =2 Name= Capital cost Component ID= subcatchment 1 and local area 1 Units= Euros Magnitude= 29,500,000</p> <p>ID =3 Name= O&M cost Component ID= subcatchment 1 and local area 1 Units= Euros/year</p>	<p>Description: Increase in annual pipeline rehabilitation rate Occurrence type:: Recurring First occurrence: 2015 Frequency: once a year Time period: 25 years Location: Distribution mains Variables:</p> <p>ID =1 Name= Leakage Rate Component ID= subcatchment 1 Units=% Magnitude= 0.5</p>

INTERVENTION STRATEGY ID	INTERVENTION STRATEGY DESCRIPTION (NAME)	INDIVIDUAL INTERVENTION 1	INDIVIDUAL INTERVENTION 2	INDIVIDUAL INTERVENTION 3
		<p>Name= Allocation of green water from RWH tank for Toilet consumption</p> <p>Component ID= subcatchment 1 and local area 1</p> <p>Units=-</p> <p>Magnitude =True</p> <p>ID =5</p> <p>Name= Allocation of green water from RWH tank for industrial consumption</p> <p>Component ID= subcatchment 1 and local area 1</p> <p>Units=-</p> <p>Magnitude =True</p> <p>ID =6</p> <p>Name= Allocation of green water from RWH tank for irrigation consumption</p> <p>Component ID= subcatchment 1 and local area 1</p> <p>Units=-</p> <p>Magnitude =True</p>	<p>Magnitude = 750,000</p> <p>ID =4</p> <p>Name= Allocation of green water from GWR tank for Toilet consumption</p> <p>Component ID= subcatchment 1 and local area 1</p> <p>Units=-</p> <p>Magnitude =True</p> <p>ID =5</p> <p>Name= Allocation of green water from GWR tank for industrial consumption</p> <p>Component ID= subcatchment 1 and local area 1</p> <p>Magnitude =True</p> <p>ID =6</p> <p>Name= Allocation of green water from GWR tank for irrigation consumption</p> <p>Component ID= subcatchment 1 and local area 1</p> <p>Units=-</p> <p>Magnitude =True</p>	



trust

TRANSITIONS TO THE URBAN WATER SERVICES OF TOMORROW

Final report with DSS methodology, software and case study
from an idealized pilot city
D 54.3

© TRUST 2015

The research leading to these results has received funding from the European Union
Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 265122.

This publication reflects only the author's views and the European Union is not liable for
any use that may be made of the information contained therein.

