Decision support system for metabolism-based transition to urban water systems of tomorrow

Mark Morley, Kourosh Behzadian, Zoran Kapelan and Rita Ugarelli

ABSTRACT

A decision support system (DSS) tool for the assessment of intervention strategies in an urban water system (UWS) with an integral simulation model called ‘WaterMet2’ is presented. Lists of intervention options and performance indicators are exposed by the DSS for the user to define intervention strategies and metrics for their comparison. The quantitative and risk-based metrics are calculated by WaterMet2 and risk modules, while the qualitative metrics may be quantified by external tools feeding into the DSS. Finally, a multi-criteria decision analysis approach is employed in the DSS to compare the defined intervention strategies and rank them with respect to a pre-specified weighting scheme for different scenarios. This mechanism provides a useful tool for decision makers to compare different strategies for the planning of UWS with respect to multiple scenarios. The suggested DSS is demonstrated through the application to a northern European real-life case study.

Mark Morley (corresponding author)
Kourosh Behzadian
Zoran Kapelan
Centre for Water Systems, College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter EX4 4QF, UK
E-mail: M.S.Morley@exeter.ac.uk
Rita Ugarelli
SINTEF Building and Infrastructure, Forskningsveien 3b, Oslo NO-0314, Norway

Key words | decision support system, indicator, intervention strategy, risk, WaterMet2

INTRODUCTION

Urban water systems (UWS) face the long-term perspective of constraints and challenges associated with climate change and the 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 in the water industry. However, it is suggested that the impact on the UWS of these technologies, prior to their practical implementation, is best evaluated by a decision support system (DSS). This approach has attracted attention by practitioners and researchers in recent years, leading to the development of tools such as AQUACYCLE (Mitchell et al. 2001), UWOT (Makropoulos et al. 2008), UVQ (Mitchell & Diaper 2010), City Water Balance (Mackay & Last 2010) and WaterMet2 (Behzadian & Kapelan 2015a). Despite a plethora of DSS being developed in recent years, relating to the integrated modelling of UWS, there remain outstanding issues which need to be addressed in this framework. The principal concern relates to simultaneously covering the whole range of sustainability dimensions in the performance indicators (PIs), including both quantitative and risk-based ones. Ideally, the PIs should reference all facets of sustainability including social, environment, economic, governance and assets (Alegre et al. 2012).

This paper presents a DSS which implements a tool which is able to quantify the impact of different sets of interventions/technologies on the performance of the UWS, including associated risks and costs, by evaluating a wide variety of sustainability PIs under different scenarios. The WaterMet2 model (Behzadian et al. 2014), which undertakes the simulation of the integrated modelling of UWS, is employed in the DSS presented. In the following section, a brief description of the DSS configuration is followed by a review of WaterMet2. The principal stages of the DSS are mapped through four steps including (1) problem definition, (2) metric calculation/decision matrix population, (3) ranking and (4) result viewing/modification/re-evaluation. The capabilities of the developed DSS are demonstrated on a real-life UWS in northern Europe. By way of the real case study, the paper presents a walk-through for each stage,
presenting a list of the scenarios, intervention strategies and metrics used. The values obtained after running the WaterMet$^2$ model and the risk module are shown, along with how those outputs are used in the population of the multi-criteria decision analysis (MCDA) decision matrices.

**DSS METHODOLOGY**

The DSS developed seeks to support long-term, strategic-level planning of UWS at the city/system level. This is achieved through a new methodology for comparison and selection of alternative solutions, within the framework of long-term transition paths, and amidst multiple decision criteria (Morley et al. 2012). The support offered to the decision maker takes several forms and guides the user through the description of alternative intervention options and scenarios. The structure of the classes in the DSS engine is split into three principal modules (Figure 1): (1) ‘Environment’, (2) ‘Performance’ and (3) ‘MCDA’. These modules are described below in further detail.

**Environment module**

The ‘Environment’ part manages the specifications of the analysis, including timing, intervention strategies, PIs, scenarios and customised model input. Basically, this module assists the user in defining the Environment configuration – i.e. the outline definition of the problem to be analysed. More specifically, the following steps are taken in this module:

- Defining a time horizon for the analysis, along with the intermediate times at which Interventions may take place.
- Defining scenarios which comprise varying input parameters to the analysis tool (i.e. WaterMet$^2$ model) or to custom metrics defined outside of WaterMet$^2$. 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 WaterMet$^2$.

![Figure 1](https://iwaponline.com/ws/article-pdf/16/3/855/412547/ws016030855.pdf)
• Selecting the performance metrics of interest to be used for evaluation from the list of available PIs, including those supported by the WaterMet\(^2\) model and those supported by other tools outside the DSS.

• Defining intervention strategies based on the list of available intervention options. Each intervention strategy comprises a set of individual interventions, including technologies and their operation on different parts of the UWS, each of which is assumed to occur at a specific time over a defined planning horizon. The DSS supports an existing library of individual intervention options quantified by WaterMet\(^2\) based on different components in the UWS.

Performance module

The ‘Performance’ part undertakes the responsibility of evaluating the performance metrics, which are split into two categories: (1) performance assessment of quantitative metrics, including non-risk-based and risk-based metrics calculated by the WaterMet\(^2\) and Risk section, respectively; (2) qualitative metrics of the aforementioned types, defined within the DSS and quantified by external tools outside the immediate scope of the DSS. The PIs calculated or supported by the WaterMet\(^2\) directly, such as risk-based metrics, are automatically populated in the DSS, whilst others evaluated outside the DSS need to be supplied manually by the user. Through repeated execution of the WaterMet\(^2\) model, each intervention strategy is evaluated to determine its effect on urban water cycle system performance. This is achieved by, firstly, applying each scenario defined in the Environment configuration in turn and also applying each intervention 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.

As a part of the built-in simulation model in the DSS, the WaterMet\(^2\) model is used to calculate all non-risk-based performance metrics and support risk-based performance metrics (Behzadian & Kapelan 2015b). In fact, the WaterMet\(^2\) model is used in the DSS for metabolism simulation of UWS for a long-term planning horizon. WaterMet\(^2\) is a conceptual and metabolism-based model which simulates water-related and other resource flows (e.g. energy, materials and environmental categories) throughout the UWS components (Behzadian & Kapelan 2015a). WaterMet\(^2\) is able to model three main subsystems of UWS (i.e. water supply, stormwater and wastewater) in different spatial (i.e. indoor, local, sub-catchment and system area levels) and temporal (i.e. daily, weekly, monthly and annual) scales. WaterMet\(^2\) adopts a daily mass-balance-based approach for modelling water flows and other fluxes. Once water-related flows are tracked down for each UWS component by simulating the integrated UWS in each time step, other fluxes (e.g. greenhouse gas (GHG) emissions) can be quantified in the UWS spatially and temporally based on associated impact coefficients. Thus, the physical metabolism of this integrated UWS is quantified through some PIs using the WaterMet\(^2\) model. Further details of the principal flows and storages modelled in WaterMet\(^2\), as well as descriptions of the components and their functionality, can be found in Behzadian et al. (2014).

The risk assessment is calculated 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 1). The likelihood scale needs to be as

<table>
<thead>
<tr>
<th>Likelihood level</th>
<th>Probability range</th>
<th>Consequence level</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Almost certain</td>
<td>( P &gt; 10% )</td>
<td>E–Med.</td>
</tr>
<tr>
<td>4 Likely</td>
<td>( 2% &lt; P \leq 10% )</td>
<td>D–Med.</td>
</tr>
<tr>
<td>3 Moderate</td>
<td>( 1% &lt; P \leq 2% )</td>
<td>C–High</td>
</tr>
<tr>
<td>2 Unlikely</td>
<td>( 0.2% &lt; P \leq 1% )</td>
<td>B–High</td>
</tr>
<tr>
<td>1 Rare</td>
<td>( P \leq 0.2% )</td>
<td>A–Low</td>
</tr>
</tbody>
</table>

The consequence levels are defined by the range of consequence and are assumed here as the measure of severity of consequences. The consequence levels are scaled in five levels: E–Med., D–Med., C–High, B–High, A–Low.
objective as possible. The probability of a risk event is assumed here to follow corresponding scenarios. For example, the probability of a risk event related to population growth is simplified as equivalent to the probability of the scenario of population growth. The scenario of high and low population growth was selected here to illustrate the methodology. For example, it is assumed that the probability of exceeding the upper limit of the 90% confidence interval is equal to 5% ([100%-90%]/2). This means that there is a 5% probability that the population will follow the strong growth or higher, and a probability of between 1 and 2% of being lower than the lower profile. Therefore, assuming Table 1 as reference scale, the probability level is set to 4 ‘likely’ and 5 ‘moderate’, respectively.

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. Consequences are defined here as five levels (A–E) of deviations of absolute value of risk event from a specified sustainability target value (Table 1). 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, in which A is the most severe consequence level and E is the least severe). 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 in Table 1. 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. Following the ranking, the decision maker is supported in interactively modifying the intervention strategies and submitting them for the 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 strategy rankings.

**MCDA module**

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. 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. Two well-known MCDA techniques are implemented in the DSS for the purpose of ranking intervention strategies: compromise programming (CP) (Zeleny, 1973) and the analytic hierarchy process (AHP) (Saaty, 1980), although the design does not preclude adding other techniques, including optimization. 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 a different way. In the CP method, user preferences are specified as multiple evaluation 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. This requires more experience to configure and employ the method. The DSS will enable the user to select the method to use when solving a particular problem, including the possibility of using both methods on the same problem and then comparing results (e.g. to see if there is an alternative solution that is ranked highly regardless of the MCDA method used). Further details of these techniques can be found in Behzadian et al. (2015).

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. Following the ranking, the decision maker is supported in interactively modifying the intervention strategies and submitting them for the 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 strategy rankings.

**CASE STUDY**

**Introduction**

The UWS of a northern European city is used here as a reference city for the case study, combined with assumptions when necessary. The existing UWS comprises two main
surface water resources connected to corresponding water treatment works (WTWs), service reservoirs, distribution mains and eventually water consumption points. The existing sewer network represents a mix of combined and separate sewers which are connected to two wastewater treatment works (WWTWs). Treated wastewater from WWTWs and untreated wastewater/stormwater from combined sewer overflows of sewer networks are discharged into a single receiving water body (i.e. downstream sea). The DSS is demonstrated here for conditions of likely future population growth. Hence, increased water demand as a result of highest foreseen population growth is the key driver which is likely to impose significant strains on the UWS performance. In the first instance, the DSS needs to have specified scenarios, intervention strategies and metrics and associated target/goals and preferences, described in the following sections.

Scenarios

In order to demonstrate the efficacy of the DSS, the following two scenarios related to high (Scenario 1) and low (Scenario 2) population growth are considered in this case study. In this instance, the WaterMet² parameters changed in these population growth scenarios are the different water demand categories (i.e. household/population growth, industrial/commercial growth and irrigation growth).

Intervention strategies

Three types of intervention options are employed in this case study:

1. Addition of a new water resource along with two WTWs.
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 metabolism model is analysed in this demonstration based on the following seven alternative UWS intervention strategies against a 30 year planning horizon (2011–2040). Note that the intervention strategies numbered 3 to 7 start from 2015.

1. Business as usual.
2. Addition of a new water resource along with two WTWs starting from 2020.
3. One percent additional annual pipe rehabilitation starting from 2015.
4. Addition of RWH and GWR systems at a local level by 25% of households starting from 2015.
5. Addition of RWH and GWR systems at a local level by 25% and 50% of households, respectively, starting from 2015.
6. Addition of RWH and GWR systems at a local level by 50% of households starting from 2015.
7. Addition of RWH and GWR systems at a local level by 25% of households and 0.5% additional rehabilitation annually starting from 2015.

Performance metrics

Six metrics according to the performance criteria of sustainability dimensions of water systems (Alegre et al. 2012) are considered for the purposes of this case study. These metrics include three quantitative criteria (C₁–C₃), two quantitative risk-based criteria (C₄, C₅) and a single qualitative example. The quantitative metrics are directly calculated by WaterMet² and risk modules, respectively. The qualitative metric (C₆) is quantified by relevant experts and the quantified values incorporated in the DSS. Instead of using qualitative categories (linguistic terms) for metric C₆, 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). Furthermore, for the risk-based metrics, failure times shorter than the time step in the simulation model (i.e. daily in the WaterMet² metabolism model) cannot be captured by the DSS. A brief description of these metrics is outlined below:

1. Reliability of water supply (C₂): the ratio of water delivered to customers to the total water demand.
2. Total cost (C₃): 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.
3. GHG emissions (C₄): annual average of the aggregated greenhouse gas emissions, as Global Warming Potential...
(GWP100) measured in units of carbon dioxide equivalents (CO$_2$-eq) from all components of the UWS.

4. **Days with restrictions to water service (C$_4$):** the risk of the annual days with restriction (water supply failure) being greater than the target value.

5. **Prolonged hydraulic failure (C$_5$):** the risk of annual expected value for the time length of hydraulic failure being greater than a target value.

6. **Social acceptance (C$_6$):** the extent to which an intervention strategy would be supported by society, especially water consumers, in order to fulfill the water demands with respect to a number of factors, especially safety and health issues.

## RESULTS AND DISCUSSION

The results are presented in the following two parts: (1) calculation of the quantitative and risk-based metrics for each intervention strategy; (2) ranking the intervention strategies using MCDA. The expert-quantified values for the single qualitative metric are directly populated in the decision matrix.

The time-series of the quantitative metrics (C$_1$–C$_3$) over the planning horizon are calculated by the DSS by running the WaterMet$^2$ model with respect to each scenario and intervention strategy. The single value for each of these metrics is calculated and populated in Table 2 for each of the two scenarios.

The risk-based metrics (C$_4$, C$_5$) are calculated based on the following sequential steps (Ugarelli *et al.*, 2014): (1) likelihood of risk event; (2) consequence levels from the PIs calculated by WaterMet$^2$ for each scenario; (3) risk estimation. The likelihood of risk events is assumed to correspond to the probability of scenarios, i.e. 4 ‘likely’ and 3 ‘moderate’ for the high and low population rate scenarios (1 and 2), respectively. Assuming a target value of 1% and 100%, respectively, for risk events of water supply failure (C$_4$) and prolonged hydraulic failure (C$_5$), the consequence scales of deviation value in Table 1 are defined as follows, respectively:

\[ E < 5\% < D < 20\% < C < 40\% < B < 60\% < A \]
\[ E < 20\% < D < 50\% < C < 85\% < B < 90\% < A \]

Given the maximum value experienced being used to aggregate the risk-based metrics over the planning horizon, the consequence levels of risk events can be calculated as shown in Table 3. With the given likelihood and consequence levels, the risk is then estimated according to the risk matrix of Table 1 for each intervention strategy and scenario, the results of which are further illustrated in Table 3.

### Table 2 | MCDA decision matrix and rankings for Scenarios 1 and 2

<table>
<thead>
<tr>
<th>Criteria/metrics</th>
<th>Reliability of water supply</th>
<th>Total cost</th>
<th>GHG emissions</th>
<th>Risk of restriction to service</th>
<th>Risk of hydraulic failure</th>
<th>Social acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>%</td>
<td>M Euros/year</td>
<td>$10^3$ Tons/year</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Weights</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Goal</td>
<td>Maximize</td>
<td>Minimize</td>
<td>Minimize</td>
<td>Minimize</td>
<td>Maximize</td>
<td>Maximize</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Strategy 1</td>
<td>94</td>
<td>99</td>
<td>53</td>
<td>52</td>
<td>95</td>
<td>89</td>
</tr>
<tr>
<td>Strategy 2</td>
<td>100</td>
<td>100</td>
<td>74</td>
<td>72</td>
<td>99</td>
<td>90</td>
</tr>
<tr>
<td>Strategy 3</td>
<td>96</td>
<td>100</td>
<td>58</td>
<td>57</td>
<td>96</td>
<td>89</td>
</tr>
<tr>
<td>Strategy 4</td>
<td>98</td>
<td>100</td>
<td>62</td>
<td>61</td>
<td>90</td>
<td>83</td>
</tr>
<tr>
<td>Strategy 5</td>
<td>98</td>
<td>100</td>
<td>63</td>
<td>62</td>
<td>89</td>
<td>82</td>
</tr>
<tr>
<td>Strategy 6</td>
<td>99</td>
<td>100</td>
<td>71</td>
<td>69</td>
<td>89</td>
<td>81</td>
</tr>
<tr>
<td>Strategy 7</td>
<td>98</td>
<td>100</td>
<td>64</td>
<td>63</td>
<td>90</td>
<td>83</td>
</tr>
<tr>
<td>Rank</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
**Ranking results**

The aforementioned metric values calculated for each intervention strategy are used to populate the corresponding MCDA decision matrix, as per Table 2, for each of the two scenarios, respectively. As the qualitative risk levels reported in Table 3 cannot directly be used for a quantitative comparison between the intervention strategies, they are rated on a scale between 1 and 3 as: high (3), medium (2) and low risk (1).

Following the population of the decision matrices, the ranking of intervention strategies is undertaken by means of the CP method (Zeleny 1973). The outputs of this ranking can be seen in the two right-most columns of Table 2. In this table, equal metric weights have been used to rank the strategies.

To further analyse the sensitivity of the ranking to the metric weights of the metrics, two further weighting schemes, including Water Company and Consumer perspectives, have been ranked by the MCDA (Table 4).

Given the three weighting schemes and two scenarios, a total of six groups of ranking for the intervention strategies are obtained, illustrated in Table 5. Naturally, there are several ways that these rankings can be merged together to achieve a final ranking for each intervention strategy. In this instance, the sum of the ranks of each strategy is used for determining final ranking, as shown in the last column for each scenario in Table 5.

As can be seen, Strategy 2, which has been consistently ranked highly, is selected in the top strategy for both scenarios. However, it is further seen that if there is low population growth (Scenario 2), Strategy 7 is ranked first due to its consistent high rank when seen from all perspectives. Strategy 1 has the lowest final rank because it has been identified as the worst strategy for several scenario/weighting combinations. Therefore, while Strategies 2 and 7 are recommended as the best strategies to adopt in this simple example, Strategy 1 is clearly not to be recommended. However, further analysis will be required to fully cover and test different criteria for these strategies.

### Table 3 | Deviation values and risk estimation for risk-based metrics; H – high, M – medium, L – low

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th></th>
<th>Scenario 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C4 [%]</td>
<td>C5 [%]</td>
<td>C4 [%]</td>
<td>C5 [%]</td>
</tr>
<tr>
<td>1</td>
<td>99</td>
<td>4</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>64</td>
<td>8</td>
<td>D</td>
</tr>
<tr>
<td>3</td>
<td>99</td>
<td>4</td>
<td>A</td>
</tr>
<tr>
<td>4</td>
<td>73</td>
<td>4</td>
<td>A</td>
</tr>
<tr>
<td>5</td>
<td>55</td>
<td>4</td>
<td>B</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>4</td>
<td>C</td>
</tr>
<tr>
<td>7</td>
<td>60.4</td>
<td>4</td>
<td>A</td>
</tr>
</tbody>
</table>

### Table 4 | Weights of the metrics from different perspectives

<table>
<thead>
<tr>
<th>Reliability of supply</th>
<th>Total costs</th>
<th>GHG emissions</th>
<th>Risk of restriction to service</th>
<th>Risk of hydraulic failure</th>
<th>Social acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal weight</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Consumer</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Water company</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
CONCLUSIONS

A new DSS was developed to facilitate decision-making for the long-term city metabolism planning problem. The new DSS methodology comprises creation of alternative intervention strategies within the framework of long-term transition paths and then comparison and selection of strategies accommodating multiple decision criteria. The DSS is able to deal with uncertain future scenarios and differing stakeholder perspectives. The DSS is able to employ a metabolism based model (WaterMet²) and risk modules to evaluate quantitative metrics of intervention strategies in an UWS over a long-term planning horizon under different scenarios (e.g. population growth). 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. For each intervention strategy in the decision matrix, the DSS can also include qualitative metrics (e.g. social acceptability) quantified by experts outside the DSS. The DSS is able to rank intervention strategies using the CP MCDA method operating over different weighting schemes, allowing the consideration of the case study from different stakeholder perspectives. The strategies which are consistently ranked highly are identified as being the likely appropriate strategies to be implemented. These strategies can be considered for further analysis, such as inclusion of other metrics. The results obtained in the case study demonstrate how the DSS developed and presented here can be used to effectively and efficiently assist planners in making better, more objective and strategic level decisions with respect to meeting the future long-term goals and performance targets in their UWS/city.

ACKNOWLEDGEMENTS

This work was carried out as part of the ‘TRansition to Urban water Services of Tomorrow’ (TRUST) project funded in the EU 7th Framework Programme under Grant Agreement No. 265122. The authors also wish to thank NTNU, Oslo VAV, LNEC and Addition (TRUST project partners) for their collaboration. Readers interested in receiving the DSS and WaterMet² model for research purposes may contact the authors.

REFERENCES

Behzadian, K. & Kapelan, Z. 2015b Advantages of integrated and sustainability based assessment for metabolism based


Behzadian, K., Morley, M. S., Vitorino, D., Coehlo, S., Ugarelli, R. & Kapelan, Z. 2015 Final report with DSS methodology, software and case study from a pilot city, Deliverable 54.3. TRUST Project.


First received 16 June 2015; accepted in revised form 12 January 2016. Available online 2 February 2016.