ASSESSING THE RELATIVE SUSTAINABILITY OF MANAGEMENT SOLUTIONS USING MULTI-CRITERIA TECHNIQUES

Crina Oltean-Dumbrava [1] and Richard Ashley [2]

1. Senior Lecturer, School of Engineering, Design & Technology, University of Bradford, UK.
2. Professor, Pennine Water Group, Department of Civil & Structural Engineering, University of Sheffield, UK.

Abstract

The SWARD (Sustainable Water industry Asset Resource Decisions) research project funded by EPSRC and the Water Industry has developed a set of decision support processes (DSP) to assist Water Service Providers (WSPs) to assess the relative sustainability of water/wastewater system asset development decisions.

The disposal of gross sanitary waste (SW) via the WC, causes major problems for the operators of UK wastewater systems (e.g. blockages, deposition and sludge disposal problems) and leads to significant impacts on the environment via overflow discharges and 'escape' through screens. A case study has investigated six possible options for dealing with the problems of sanitary waste escape. These include end of pipe solutions, input reduction solutions and in-sewer storage solutions.

The selection of criteria, data assembly and the use of three multi-criteria analysis (MCA) techniques ELECTRE III, PROMETHEE and SMART to assess the relative sustainability of the six different options under consideration are presented.

Keywords: Decision making, Multi-criteria analysis techniques, Sustainability, Sustainability Criteria, Sanitary Waste Escape

Introduction

It is estimated that 2.5 million tampons, 1.4 million sanitary towels and 700,000 panty liners are disposed of by WC every day in the UK. Of great concern is the increase in the amount of plastic being used in these items and changes in public usage patterns. Numbers and weights being disposed of are unlikely to reduce in the foreseeable future, even with government and other minimisation initiatives. The problems for wastewater system operators caused through disposal of sanitary waste (SW) items via the WC include: blockages; increased requirement for sewer maintenance; increased loads to wastewater treatment plants – necessitating screens; and significant impacts on the environment via overflow discharges and 'escape' through screens.

It is apparent that the best way of managing this waste needs to be determined both for the present and the future. A case study has investigated the problem of domestic sanitary waste escape in a catchment, using the SWARD (Sustainable Water industry Asset Resource Decisions) decision support processes (Ashley et al 2004). Six possible options for dealing with the problem of sanitary waste escape have been generated for assessment. These include a public information campaign, end-of-pipe solutions, the retrofitting of constricting WCs, and changes to the physical sewerage system.

The Sanitary Waste Case Study

The catchment used for the case study was a small coastal town (population c.1500) in Scotland. The catchment has 626 domestic properties, mostly detached or semi-detached. These properties have large impermeable roof areas, and the majority also have drives of which about 30% are porous (paving or gravel). A large portion of the town's developed area is on high ground above the original coastal floodplain. The catchment is served by 80% combined and 20% surface water sewers.

The case study has required active collaboration between the three Scottish Water Authorities and the SWARD team to produce a realistic case study. The collaborators were involved in each of the phases of the Decision Support Processes (DSP) during the case study.

Multi-Criteria Analysis (MCA)

The objective of multi-criteria approaches is to help managers to make better decisions in the presence of ambiguity and uncertainty by analysing the decision-making context, identifying the number and personality of actors (stakeholders), identifying and defining the different possibilities of actions (decisions), their consequences and stakes. This is done by getting the actors to cooperate in the decision-making process. A set of decision criteria is defined and proposed to facilitate a better mutual understanding of the decision-making framework, which is favourable to debate. The types of consequences and attributes defining the criteria are identified together with their imprecision, inaccurate determination and the conditions these criteria should satisfy. Comprehensive comparisons can then be made by quantifying the preference information related to the specific role of each criterion due to its own importance. These comprehensive comparisons are made using aggregation mathematical models that can use a synthesizing single criterion or more outranking relations of logic procedures which generate the required output of the decision process, namely the final selection, assignment or ranking.

SWARD sustainability criteria and indicators have been determined, and qualitative and quantitative data assembled. The precise definition of the criteria and the opportunity of their inclusion in the multi-criteria decision making process was determined through a series of workshops with a number of WSPs both in Britain and Romania. A separate workshop was organised with a number of decision-makers, academics and researchers from India experienced in the water industry. A wide range of techniques have been used to collect the information required, including Life Cycle Assessment (LCA) hydraulic modelling and surveys of public attitudes.

These criteria are classified under four categories, which aim to encapsulate the economic, environmental and social principles of sustainability, together with technical criteria, which relate primarily to the ability of the water/wastewater system to sustain and enhance the performance of the functions for which it is designed.

Within each category, a small number of primary criteria are specified. Under each of these primary criteria, a larger number of secondary criteria are specified. These can be used as the basis for indicators to assess the future performance of the water/wastewater system under the particular development option under scrutiny, in order to assess whether the system is moving towards or away from sustainability. The secondary criteria give more case specific types of impact under these headings (Foxon et al. 2002).

In the case study the pertinent primary criteria have been selected or informed by the generic list but were specifically defined for the given decision objective, to allow the assessment of the relative sustainability of the six options given in Table 1. Table 2 presents the primary criteria, secondary criteria and attributes used in the case study and Table 3 the full set of data collected that was used for all three MCA methods.

The criteria were discussed and validated at a steering group meeting with senior representatives from the water industry. A workshop was also held involving members of staff from a water authority with the aim of weighting the importance of the selected criteria in the decision making process. A range of activities was completed in the workshop, involving individual ranking, placing the criteria into categories, and ranking the four categories of sustainability criteria. The results of the SWARD workshops in particular highlight the difficulties faced when entering into processes that require the ranking or weighting of criteria, categories or indicators for decision support purposes (Table 4, 5 and 6). A group discussion took place at the end of the workshop in which the group rankings and categorisation of criteria were agreed. A further meeting with a water industry 'decision maker' allowed data to be obtained on preferences, indifference values and veto levels for all the criteria, which were needed for input into Multicriteria Analysis models. In this way the SWARD team could determine the weighting of the criteria for both situations, namely single decision-makers and group decision-makers, thus allowing a comparison of the two to be made.

Three MCA methods were used in the case study: ELECTRE (Roy 1978, Roy et al. 1992), PROMETHEE (Vincke 1992) and Simple Multiple Attribute Rating Technique (SMART) to help the decision-maker to find a preferred option among the 6 identified that will manage better the sanitary waste taking into account the defined 16 criteria (Oltean-Dumbrava et al. 2004). These methods were selected for the following reasons:

- PROMETHEE and ELECTRE III are non trade-off methods that can be used in strategic, complex decision-making problems, that have far reaching consequences in time or involve substantial capital costs. One of the differences between these two methods is that PROMETHEE has six predefined value functions. As such its use is recommended only if the criteria selected can be modelled by one of these predefined value functions. This restricts the use of this methodology.
- ELECTRE III, on the other hand, has no predefined value functions. When using this methodology one has to model these functions for each criterion individually. The methodology is more complex and can deal with a very high number of variables. By using a veto threshold unacceptable options and or values for criteria are eliminated from the analysis.
- SMART is a methodology recommended in everyday decision-making problems of a multi-criteria nature. The major weakness of this model is that it is a trade-off method and can be used for the analysis of up to 15 criteria at the most. Its compensatory nature can mask unacceptable values for criteria.

The Electre Analysis

In the presence of a multicriteria decision problem with a finite set (6) of alternatives/options, a consistent family of 16 pseudo criteria the decision-maker needs expert help to rank these 6 options. The ranking of the 6 options, in a decreasing order of preference, is based on a fuzzy outranking relation represented by a credibility degree. The value functions developed for the 16 criteria used both the partial and complete pre-order using a descending distillation procedures by which the 'preferred' options are selected first each time from the remaining ones. The input data and parameter settings are presented in Table 7 and Table 8.

The outranking relationship between the 6 options is presented in a graphical form in Figure 1 using the descending order (from the best option to the worst option) and in Figure 2 using the ascending order (from the worst option to the best option). These two ways of ranking are called distillations. One can notice that they are slightly different. The final ranking is obtained through the average of the ranks of the two intermediate distillations and is presented in Table 9. ELECTRE III Analysis preferred option is SeRe followed by TBYF.

The Promethee Analysis

The PROMETHEE procedure is based also on pairwise comparisons. From the 6 predefined preference functions the decision-maker was asked to select the one he considered better modelled the criterion in question. The DECISION LAB 2000 software was used for the analysis. It is developed for real world applications and can perform up to 3600 evaluations. The performance matrix is presented in Table 10.

Introducing the data from Table 10 and Table 11 in the software a partial ranking was obtained using PROMETHEE I. The partial ranking is the intersection of positive and negative outranking flows. The positive (Φ+) and negative (Φ-) outranking flows are usually not identical. In this case the information of both outranking flows is consistent and may therefore be considered as reliable. The partial ranking is presented in Figure 3.

The partial ranking does not indicate which option TBYF or SeRe is better. It is up to the decision-maker to take his/her responsibility in selecting one of them. That is why the decision-maker often requires a complete ranking. This is the balance between the positive and the negative outranking flows. The higher the net flow (Φ), the 'better' the option. A complete ranking is obtained with PROMETHEE II. The complete ranking is presented in Figure 4. One can notice that only the first three options have a positive net flow.

To conclude, the final ranking obtained using the PROMETHEE methods indicates the preferred option to be TBYE followed closely by SeRe.

The Smart Analysis

As stated before SMART's main weakness is that it is a trade-off method and can be used for the analysis of up to 15-16 criteria at the most. Its compensatory nature can hide unacceptable values for criteria. The SMART analysis data are presented in Table 12.

The ranking order of Preference as determined from the SMART analysis is presented in Figure 5. SMART's preferred option is TBYF followed by RSSC.

Analyses of Results

Sensitivity analyses were performed on the analyses in order to study if the results obtained by using the three multicriteria methods form a good support for building a recommendation to the decision-maker on the possible preferred option. For elaborating recommendations to the decision-maker it is important to consider the impact of the changes of weights on the overall ranking and to ascertain if the changes are significant. In summary, taking into account the sensitivity analysis also, the ranking results for each of the options in each of the analyses are presented in Table 13.

Comparison of Results

For ease of use SMART is superior, followed by PROMETHEE, as a result of its predefined value functions. The software is user-friendly and illustrates to the decision-maker (with the aid of the decision stick) the impact of changes in weights on the ranking of options. It also illustrates how each option is performing for each individual criterion. The ELECTRE III software is the most sophisticated of the three presented and as such is more difficult to use. It does not have the graphical instruments of PROMETHEE/PROMCALC, although the ranking can be presented in a graphical form. However, the most time consuming is not the analysis itself, but the data collection. Overall consideration of the results presented in Table 13 would suggest that the Think Before You Flush (TBYF) option generally dominates the top rankings, followed by sewer rehabilitation (SeRe) and then the retrofit source control (RSSC). The other three options are consistently placed in the final three positions. Whilst there would appear to be a reasonable degree of consistency between the outranking methods (PROMETHEE and ELECTRE), there is less consistency between these methods and the SMART analysis. This is likely to be due to the influence of trade-offs in the SMART analysis between positive and less positive scores for individual criteria within the analysis.

Based on the overall result and ignoring the fact that SMART is a trade-off method and as such distorting to a certain extend the results, the final ranking is presented in Table 14.

Decision-makers may not select the option that has been shown to be the more sustainable. This may be due to a number of reasons, leading to constraints that could not be fully included in the analysis above. It is the decision-maker's responsibility to consider if selecting option TBYF, the assumptions made about public changes in culture and habit are not too optimistic. The final decision depends very much on the attitude to risk the decision-maker has. Both 'investment' option SeRe and RSSC are very close in terms of their utility and can complement the TBYF option in the case of an adverse to risk or neutral to risk decision-maker. The MCA ranking is in a stark contrast with the one established on the basis of professional judgement (with no MCA) by the decision-makers in a workshop. Their ranking is presented in Table 15. This table shows that the decision-makers have top ranked the least sustainable options thus emphasising the necessity to undertake a MCA especially for strategic decisions.

In order to simulate the final decision making stage, the results of the MCA and the sensitivity analysis were presented to a group of water industry experts with different professional backgrounds. A consensus was reached that a combination of unproven methods, which were generally identified by the MCA analysis as being more sustainable, and a complementary proven method was the appropriate approach to the problem. The final decision was taken to adopt a combination of TBYF and screen solutions with the screen providing a safety net if the TBYF campaign proved unsuccessful. This was deemed particularly important for this catchment as it was a holiday resort. In such catchments, holidaymakers may not have the same knowledge and understanding of sanitary waste issues and therefore screens may still be required. However, it was noted that when screen replacement was required (in ca. 20 years), the success of the TBYF campaign could be established and the screen may ultimately prove to be unnecessary.

Conclusions

This case study has illustrated the application of the SWARD DSPs to compare the relative sustainability of a range of options for the management of SW. The outputs from three MCA models indicate that the traditional engineering solutions are less sustainable than the alternative options explored. Running public education campaigns appears to be the *most sustainable* of the six options. Institutional systems and regulatory targets in the UK sometime encourage the adoption of less sustainable technologies or solutions, hence the continuing reliance on screening and in-sewer storage. Despite the recognition of the need to contribute to sustainable development expressed by the industry and its regulators, sustainability issues are not properly reflected in the way in which performance targets are set, and the financial determinations allow only for the achievement of current performance standards within very short (5 year) timescale. Without a dramatic and fundamental change in the way in which these organisations operate, the move towards establishing more sustainable water/wastewater infrastructure is sure to be laborious.

The results of the SWARD workshops in particular highlight the difficulties faced when entering into processes that require the ranking or weighting of criteria, categories or indicators for decision support purposes. A range of explicit and implicit factors will always influence the value systems expressed, both in individuals and within a group.

The way that workshop questions are posed will also have an effect on the interpretation and thus the outcome, and whether an individual or negotiated group approach is used for stakeholder involvement in any project is likely to significantly affect the results of any ranking and weighting exercises undertaken. This emphasises the fact that dealing with the value systems of any stakeholder group/s is not as straightforward a task as is often portrayed, and this caveat should be borne in mind by all those involved in participatory exercises. However, despite the wide range of professional participants that took part in the SWARD workshops, some commonalities run through the results. The dominance of economic criteria as the most important of the SWARD categories in most workshops is perhaps unsurprising, cost ultimately being a major decision driver across all social and environmental transactions. Decision makers are accountable mainly in terms of costs and individuals will always think firstly in terms of financial affordability. Another explanation could be that decision makers and other stakeholders are more comfortable with quantitative criteria than with the more qualitative criteria. Although the latter may be measurable in particular 'units of measurements' these are, ultimately, always going to be less tangible than those that are expressed in more readily accepted financial value terms. This last aspect will make the measurement of sustainability more difficult.

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Crina Oltean Dumbrava. Senior Lecturer, School of Engineering, Design & Technology, University of Bradford, Bradford, BD7 1DP, UK. Tel.: +44(0)1274 233646. Fax: +44(0)1274 234525.
E-mail: m.c.a.oltean-dumbrava@bradford.ac.uk

Richard Ashley. Professor, Pennine Water Group, Department of Civil & Structural Engineering, University of Sheffield, Sheffield, S1 3JD, UK. Tel.: +44(0)114 222 5766. Fax: +44 (0)114 222 5700.

Option	Objective	Measures	Description
A *End of pipe solution*	To meet the minimum discharge requirement for aesthetic pollution	*A1 Install 6mm screens (or equivalent) at the storm overflow.* (In6S)	There is a storm overflow at the town's wastewater treatment plant, which serves the storm/emergency overflow, discharging to a long sea outfall. The 12mm bar screen serving this outfall will be replaced by a 6mm drum screen or similar technology. The option only meets the present requirement & the likelihood of the standard changing should be taken into account.
B *Habit change*	To achieve a sustained reduction in the number of SW items disposed by the waterborne route, ideally removing them entirely from the waterborne system.	*B1 Educational approach to habit change.* (TBYP)	The 'Think Before You Flush' (TBYF) campaign highlights the issue of SW & educates the public about the effect of flushing & encourages alternative disposal practices. However, the reduction in the number of items disposed of via WC cannot be guaranteed as this relies on the behaviour of individuals in private.
		B2 Retrofit/fit low-flush small-bore outlets to existing/new WCs (ROC)	Small-bore outlets on WCs will stop the flushing of large items of SW. This will force the public into using alternative methods of disposal. This method will also require education of the user regarding the smaller items that will still flush e.g. cotton buds.
C *Spill reduction*	To reduce flows in the sewer system, so that the overflows operate less frequently, discharging less SW to the environment. However, just as much SW will reach the treatment plant as currently.	*C1 In-sewer storage* (InSt)	Increasing storage within the sewerage system will reduce the effect of increases in flow due to rainfall. Storage provides flow equalisation & reduces the peak flow rate. Storage may be in the form of on- or off-line storage tanks. Flow stored in the tanks is then drained & treated at the WwTW as the storm recedes.
		C2 Source control of storm drainage (RSSC)	Overflows occur entirely due to storm drainage. This approach is designed to reduce storm-water flows. Sustainable Urban Drainage Systems (SUDS) can be used to reduce storm water input to the combined sewer. Source control systems are typically situated immediately alongside the surfaces they serve. For example, control by Minimising Directly Connected Impervious Areas (MDCIA) in the form of rainwater barrels will be implemented, as parts of the impermeable areas are already connected to infiltration systems (porous drives etc.).
		C3 Sewer rehabilitation (SeRe)	Infiltration into the sewerage system contributes significantly to the flows during both dry & wet weather; hence this increases the CSO spills. The reduction of infiltration can be achieved by sewer rehabilitation by re-lining or other means.

Table 1. The Six Options Generated for the SW Case Study

Primary SWARD criteria	Secondary criteria (& criteria code)	Indicator	Method of collection
Life Cycle Costs	E1: Capital cost: Investment (CC) E2: Operation Costs (OC) E3: Maintenance Costs (MC)	£ per catchment £ per catchment per annum £ per catchment per annum	Cost estimation for investment - consultation Cost estimation - consultation Cost estimation for investment - consultation
Financial Risk Exposure	E4: Financial risk exposure (FRE)	Qualitative expression of estimated risk	Consultation
Resource utilisation	EV1: Energy Use (EnUs)	Total energy (MJ) for 20 year life cycle	Life Cycle Analysis
Environmental impact	EV2: Impact on air IoAC IoAN IoAS	Total CO_2 emissions (kg) for 20 year cycle Total NOx emissions (kg) for 20 year cycle Total SO_4 emissions (kg) for 20 year cycle	Life Cycle Analysis
CSOD	EV3: CSO/SO discharges to the environment	Volume per annum (cu.m)	InfoWorks modelling
Acceptability to stakeholders	S1: Acceptability to stakeholders (customers) (AcSt) S2: Perceived impact on the environment (PIE)	Percentage acceptability (Qualitative) Percentage perceiving negative environmental impact (Qualitative)	Door-to door Questionnaire Door-to door Questionnaire
Participation and responsibility	S3: Participation and responsibility (PaRe)	Level of participation required for option, High –low (Qualitative)	Consultation with water authority staff/SWARD team members
Performance	T1: Sanitary Waste Escape (SWE)	Quantity discharged to receiving watercourse per annum (kg)	Infoworks modelling, Mass Balance + screen performance information
	T2: Sanitary Waste Transport In Sewer (SWT)	Amount of sanitary waste detained in sewer system per annum (High – low)	Consultation with water authority staff/SWARD team members
Reliability	T3: Risk of Failure to provide service (RDF)	High – low (Qualitative)	Consultation with water authority staff/SWARD team members
Flexibility and adaptability	T4: Flexibility and adaptability (FlAd)	Ability to accommodate future needs (Qualitative)	Consultation with water authority staff/SWARD team members

Table 2. SWARD Sustainability Criteria

	1. Screen In6S	2. TBYF	3. Storage InSt	4. Source control RSSC	5. Rehabilitation SeRe	6. Retrofit ROC
Sanitary Waste Escape (Kg/yr.)	5.38	36.86	52.7	89.21	70.3	6.54
SW Transport	low	low	medium	medium	high	medium
Risk of failure	very low	high	low	medium	low	very high
Flexibility & adaptability	medium	medium	low	high	low	low
Capital cost (£)	68 000	10000	70 000	3925	39 000	32 446
Operational cost (£/yr.)	628.67	800	0	0	0	800
Maintenance cost (£/yr.)	3167	0	680	0	0	0
Financial risk exposure	medium	low	high	low	low	high
Acceptability (%)	68.8	85.9	62.5	51.6	89.1	65.6
Perceived impact on environment (%)	60.9	78.1	59.4	57.8	71.9	68.8
Participation & responsibility	low	high	low	high	low	high
Energy use (MJ)	2.6E+05	1.67E+04	1.41E+06	2.16E+05	3.97E+04	1.48E+05
Impact on air - CO_2 (kg)	1.64E+04	806	1.5E+05	7.23E+03	3.13E+03	4.59E+03
Impact on air – Nox (kg)	18.9	0	1.88E+03	3.63	7.94	31.1
Impact on air – SO_4 (kg)	423	3.75	1.89E+03	44.4	15	60
CSO Discharge (m^3/yr)	58564.23	58564.23	28062.68	48480.28	38607.65	56626.74

Table 3. The Full Set of Data Collected for the SW Case Study

	Individual	*Subgroup*	*Full Group*
Acceptability to stakeholders	2	2	2
Affordability	4	4	1
Durability	11	14	12
Environmental impact	5	6	4
Financial risk exposure	15	10	11
Flexibility & adaptability	14	16	14
Health impacts	1	1	4
Life cycle costs	11	6	8
Participation & responsibility	13	3	6
Public awareness/understanding	3	9	6
Reliability	10	8	9
Resource utilisation	7	11	9
Service provision	6	5	2
Social inclusion	9	13	15
System Performance	16	15	16
Willingness to pay	8	12	13

Table 4. The differences in criteria ranking given within workshop

	Individual							Group						
Workshop number	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Economic	1	-	1	1	1	3	1	1	1	1	1	2	1	1
Environmental	3	-	2	2	1	1	3	2	3	2	1	2	1	2
Social	4	-	3	3	3	4	2	3	4	2	2	1	3	4
Technical	2	-	4	4	4	2	4	4	2	2	3	1	4	2

Table 5. Ranking of SWARD categories – individual and group results

Criteria // Profession	Engineer	Engineer	Strategy/ policy	Finance	Water qual/ environment	Water qual/ environment
Accept. to stakeholders	5	8	10	1	6	11
Affordability	3	3	5	4	9	15
Durability	8	5	11	14	14	6
Environmental impact	4	9	9	11	3	7
Financial risk exposure	13	6	6	3	15	13
Flexibility and adaptability	7	4	12	6	5	9
Health impacts	6	10	7	2	4	4
Life cycle costs	2	3	4	9	12	8
Participation/responsibility	14	12	15	16	7	12
System Performance	1	1	1	8	1	1
Awareness/understanding	12	13	13	10	7	7
Reliability	9	5	2	12	8	5
Resource utilisation	11	11	8	13	2	3
Service provision	10	7	3	7	10	10
Social inclusion	15	14	14	15	11	14
Willingness to pay	3	15	16	5	13	16

Table 6. Results of the individual criteria ranking exercise – Scottish Water Authority staff

	SWE	SWT	RoF	FlAd	CC	OC	MC	FRE	AcSt	PIE	PaRe	EnUs	IoAC	IoAN	IoAS	CSOD
In6S	5.38	0	0	0.6	68000	628.67	3167	0.3	68.8	60.9	0	260	16400	18.9	423	58564
TBYF	36.86	0	0.75	0.6	10000	800	0	0	85.9	78.1	1	16.7	806	0	3.75	58564
InSt	52.70	0.5	0.15	0	70000	0	680	1	62.5	59.4	0	1410	150000	1880	1890	28062
RSSC	89.21	0.5	0.4	1	3925	0	0	0	51.6	57.8	1	216	7230	3.63	44.4	48480
SeRe	70.30	1	0.15	0	39000	0	0	0	89.1	71.9	0	39.7	3130	7.94	15	38607
ROC	6.54	0.5	1	0	32446	0	800	1	65.6	68.8	1	148	4590	31.1	60	56626

Table 7. Performance Matrix for ELECTRE III

	SWE	SWT	RoF	FlAd	CC	OC	MC	FRE	AcSt	PIE	PaRe	EnUs	IoAC	IoAN	IoAS	CSOD
Weight	8	4	9	7	10.5	10.5	10.5	3.5	4.5	7.5	3	3.5	3.5	3.5	3.5	8
Dir. of Pref.	Decr.	Decr.	Decr.	Incr.	Decr.	Decr.	Decr.	Decr.	Incr.	Incr.	Incr.	Decr.	Decr.	Decr.	Decr.	Decr.
Mode of Def.	Direct	Direct	Direct	Direct	Inverse	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct
Indiff. Coef. α	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	1	0.3	0.2	0.39	10000	1	200	0.2	1	4	0.3	99	50000	300	250	12000
Pref. Coef α	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	19	2	0.3	2	20000	500	500	2	10	5	2	100	50000	300	250	15000
Veto Coef α	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 8. Characteristics of the Criteria

Rank	Alternative
1	SeRe
2	TBYF
3	RSSC ROC
4	InSt
5	In6S

Table 9. Ranks in Preorder

	In6S	TBYF	InSt	RSSC	SeRe	ROC
SWE	5.38	36.86	52.70	89.21	70.30	6.54
SWT	0.0000	0.0000	0.5000	0.500	1.0000	0.5000
RoF	0.0000	0.7500	0.1500	0.4000	0.1500	1.0000
FIAd	0.6000	0.6000	0.0000	1.0000	0.0000	0.0000
CC	68000.00	10000.00	70000.00	3925.00	39000.00	32446.00
OC	628.67	800.00	0.00	0.00	0.00	0.00
MC	3167.00	0.00	680.00	0.00	0.00	800.00
FRE	0.3000	0.0000	1.0000	0.0000	0.0000	1.0000
AcSt	68.8000	85.9000	62.5000	51.6000	89.1000	65.6000
PIE	60.9000	78.1000	59.4000	57.8000	71.9000	68.8000
PaRe	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
EnUS	260000	16700	1410000	216000	39700	148000
IoAC	16400	806	150000	7230	3130	4590
IoAN	18.90	0.00	1880.00	3.63	7.94	31.10
IoAS	423.00	3.75	1890.00	44.40	15.00	60.00
CSOD	58564.23	58564.23	28062.68	48480.28	38607.65	56626.74

Table 10. Performance Matrix for PROMETHEE

	Function Type	**Min/Max**	**P**	**Q**	**S**	**Unit**	**Scale**		**Weight**
SWE	III	Min	19	-	-	Kg/yr	Numerical		8
SWT	II	Min	-	0.3	-	Qualitative	Low Medium High	0 0.15 1	4
RoF	IV	Min	0.3	0.2	-	Qualitative	V.Low Low Medium High V.High	0 0.15 0.4 0.75 1	9
FIAd	II	Max	-	0.39	-	Qualitative	Low Medium High	0 0.6 1	7
CC	V	Min	20000	10000	-	£	Numerical		10.5
OC	III	Min	500	-	-	£/yr	Numerical		10.5
MC	V	Min	500	200	-	£/yr	Numerical		10.5
FRE	II	Min	-	0.2	-	Qualitative	Low Medium High	0 0.3 1	3.5
AcSt	III	Max	10	-	-	%	Numerical		4.5
PIE	IV	Max	5	4	-	%	Numerical		7.5
PaRe	II	Max	-	0.3	-	Qualitative	Low High	0 1	3
EnUS	V	Min	100000	99000	-	MJ	Numerical		3.5
IoAC	II	Min	-	50000	-	kg	Numerical		3.5
IoAN	II	Min	-	300	-	kg	Numerical		3.5
IoAS	II	Min	-	250	-	Kg	Numerical		3.5
CSOD	V	Min	15000	12000	-	Litres/yr	Numerical		8

Table 11. Parameters for Use in the Decision Lab Software

	Weight	**In6S**		**TBYF**		**InSt**		**RSSC**		**SeRe**		**ROC**	
Criteria	**(Normal)**	**Pref. Score**	**Score**	**Pref. Score**	**Score**	**Pref. Score**	**Score**	**Pref. Score**	**Score**	**Pref. Score**	**Score**	**Pref. Score**	**Score**
SWE	8	95	760	75	600	60	480	40	320	50	400	90	720
SWT	4	100	400	100	400	50	200	50	200	0	0	50	200
RoF	9	100	900	25	225	85	765	60	540	85	765	0	0
FlAd	7	60	420	60	420	0	0	100	700	0	0	0	0
CC	10.5	45	472.5	80	840	40	420	95	997.5	65	682.5	70	735
OC	10.5	85	892.5	80	840	100	1050	100	1050	100	1050	100	1050
MC	10.5	35	367.5	100	1050	80	840	100	1050	100	1050	75	787.5
FRE	3.5	70	245	100	350	0	0	100	350	100	350	0	0
AcSt	4.5	69	310.5	86	387	63	283.5	52	234	89	400.5	66	297
PIE	7.5	61	457.5	78	585	59	442.5	58	435	72	540	67	502.5
PaRe	3	0	0	100	300	0	0	100	300	0	0	100	300
EnUs	3.5	25	87.5	95	332.5	0	0	30	105	90	315	50	175
IoAC	3.5	80	280	95	332.5	70	245	85	297.5	90	315	95	332.5
IoAN	3.5	85	297.5	100	350	20	70	95	332.5	90	315	70	245
IoAS	3.5	60	210	95	332.5	10	35	85	297.5	90	315	80	280
CSOD	8	10	80	10	80	50	400	25	200	30	240	15	120
Score	(100)		61.805		74.245		52.31		74.09		67.38		57.445

Table 12. SMART Analysis

	PROMETHEE	ELECTRE	SMART
6mm Screen at storm overflow at Treatment Works	5th	6th	4th
Think before you flush	1st	2nd	1st
Install flow storage	6th	5th	6th
Retrofit stormwater source control	3rd	=3rd	2nd
Sewer rehabilitation	2nd	1st	3rd
Retrofit outlet chokes	4th	=3rd	5th

Table 13. Ranking Results for ELECTRE, PROMETHEE and SMART

Rank	Alternative
1	TBYF
2	SeRe
3	RSSC
4	ROC
5	In6S
6	InSt

Table 14. Final Ranking

Rank	Alternative
1	In6S
2	InSt
3	SeRe
4	RSSC
5	TBYF
6	ROC

Table 15. Decision-Makers’ Ranking

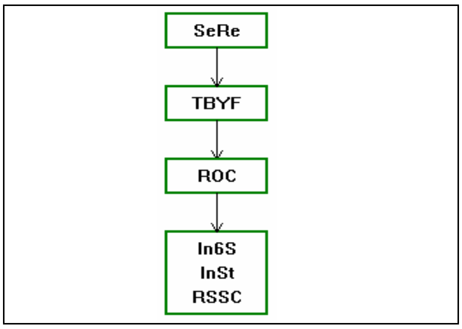

Figure 1. Descending distillation

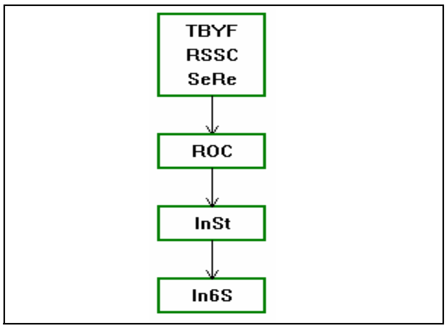

Figure 2. Ascending distillation

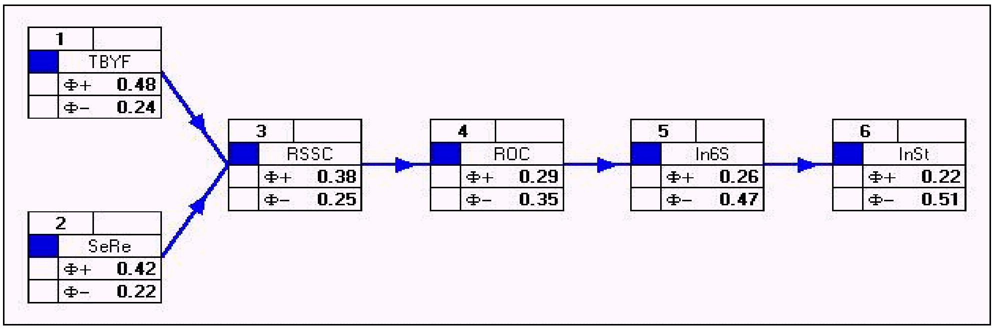

Figure 3. Partial Ranking (PROMETHEE I)

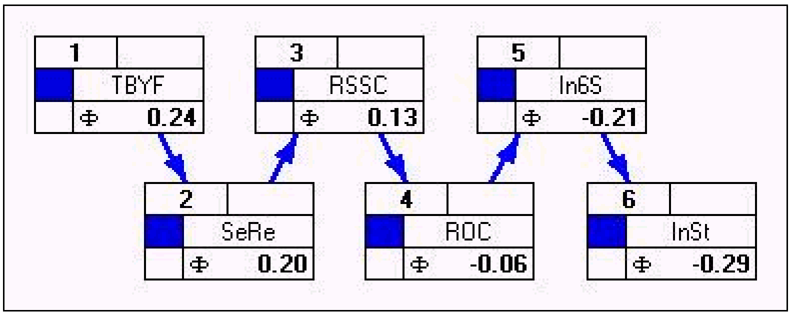

Figure 4. Complete (Final) Ranking (PROMETHEE II)

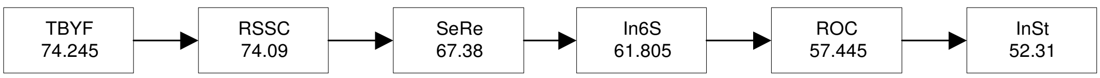

Figure 5. SMART Ranking