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Development and validation of system design principles for water reuse systems

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Abstract

Decision support software (DSS) for Water Treatment for Reuse with Network Distribution (WTRNet) has been developed within the AQUAREC project on “Integrated Concepts for Reuse of Upgraded Wastewater”, under the Fifth European Community Framework Programme. The overall objective of work conducted as part of the AQUAREC project has been the development and validation of system design principles for water reuse systems. The DSS provides an integrated framework for optimisation of treatment and distribution aspects of water reuse and the selection of end-users, and has been used in the development of the design principles. The principle components of the software (simulation and optimisation models) are presented, followed by the discussion on the software validation. A case study is then illustrated, on which WTRNet has been applied to develop least-cost design alternatives. Design principles for water reuse systems that were achieved by applying the WTRNet tool are presented, in which the importance of utilising formal optimisation in determining the most promising design alternatives is demonstrated.

Keywords: Decision support; Least cost design; Optimisation; Water reuse

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1. Introduction

Reclaimed water projects typically include construction of new or upgrades to a municipality’s treatment systems, to treat wastewater to the required quality level, and construction of distribution systems for reclaimed water. A water reuse system is likely to have many possible design options: type and degree of treatment, number and location of treatment plants, number and location of pumps/pumping stations, number, size and location of storage tanks, layout and size of distribution pipe network. These elements are all linked, to give multiple interactions and a very large number of design combinations even for apparently small systems. In addition, a large number of potential end-users of reclaimed water may exist from which a selection needs to be made on whom to provide water to, which further complicates the decision making. The complexity associated with planning of water reuse schemes is therefore very high due to a very large number of design combinations possible, and establishes the need for use of decision support systems (DSS) to aid in the planning process.

A DSS for Water Treatment for Reuse with Network Distribution (WTRNet) has been developed within the AQUAREC project on “Integrated Concepts for Reuse of Upgraded Wastewater”, under the Fifth European Community Framework Programme. The DSS provides an integrated framework optimisation of treatment and distribution aspects of water reuse and the selection of end-users, and has a broader aim of developing the design principles for water reuse systems. This paper describes the components of the DSS — simulation and optimisation models for least-cost planning of water reuse systems, and introduces a case study on which WTRNet has been applied to develop least-cost design alternatives. This is preceded by a literature review of DSS methodologies relevant to planning of water reuse schemes.

2. Review of DSS for water reuse

This section summarizes the results of a comprehensive literature review of tools relevant to the development of an integrated DSS for water reuse, dealing with wastewater treatment for reuse, distribution of reclaimed water, and integrated approaches.

Models developed in the past for synthesis of treatment trains, evaluation and screening of synthesized treatment trains, and selection of the optimum (or near optimal) treatment train used a variety of methodologies to generate and screen unit process combinations. Examples of methodologies used for wastewater treatment (with and without reuse) include enumeration techniques [1, 2], Monte Carlo simulation [3], heuristic search [4], and modelling to generate alternatives [5]. A detailed overview of these methodologies is presented in [6]. The same author presented a comprehensive approach for evaluating and optimising treatment alternatives for wastewater reuse using genetic algorithm (GA) in a DSS called MOSTWATER. Another tool developed to assist planners in evaluating treatment trains for wastewater reclamation called WAWTTAR, described in [7], is intended primarily for developing countries. Both of these models aid the user in evaluation of treatment trains from unit processes contained in their respective databases, and none offer suggestions for complete treatment trains based on local conditions. In addition, the WAWTTAR model does not include any optimisation routines.

The cost of wastewater reclamation is often cited as the key criterion for evaluation of treatment trains, although a number of other criteria have been used in the past. Metcalf and Eddy [8], for example, point out 23 important factors that should be considered when evaluating and selecting unit processes for wastewater treatment, in addition to the economic life-cycle analysis. The criteria used by other researchers vary depending on the methodology used in the selection of preferred alternatives, as well as the intended purpose of the model. In [1], cost, energy and land requirements and subjective ratings of processes were used in an implicit enumeration approach, while [9] used 50 criteria and a multi-level amalgamation technique to select an appropriate sanitation alternative for developing countries.

In the context of optimal distribution system design, a number of methodologies have been developed in the past, that consider not only the pipe-sizing problem, but also include other important aspects of water distribution system design such as cost data (e.g., whole-life costs) implications [10], reliability and redundancy of designs, uncertainty, and sizing decisions influencing future development and demands. An overview of optimisation techniques for water distribution system design can be found in [11].

The water distribution aspect of water reuse systems has also been addressed in several integrative approaches to evaluating water reuse schemes. Linear programming in combination with GIS was used in [12] to calculate and display feasible and optimal water exchange scenarios in a region, and also in [13] for basic data processing and information gathering in the development of a comprehensive urban water reuse model, which used a network flow optimization model for modelling an urban water network. This approach also included a simplified modelling of multi-level wastewater treatment processes for water reuse and employed stochastic optimization methods to quantitatively model uncertainty issues in urban water reuse planning and management. An integrative approach encompassing all relevant aspects of water reuse schemes is presented by Oron [14], which includes the transportation and storage of reclaimed water. A linear objective function was used to optimize the comprehensive system, and the optimal solution to a sample problem of wastewater reuse in agricultural irrigation was found using linear programming. Economopoulou and Economopoulos [15] presented a methodology that uses a knowledge base and inference procedures for developing rational wastewater management schemes for small to medium size communities, with emphasis on the use of natural treatment systems and reuse of treated wastewater.

3. Overview of WTRNet software

The literature review summarized in the previous section revealed that the majority of the existing decision support systems for evaluating water reuse projects focus on synthesis of treatment trains, despite the fact that “no single factor is likely to influence the cost of water reclamation more than the conveyance and distribution of the reclaimed water from its source to its point of use” [16]. The models that include the distribution aspects of reuse schemes either do not incorporate provisions for the assembly of treatment trains from individual unit processes, or consider the treatment train components in a simplified manner by considering only general levels of treatment. In addition, both the layout of the distribution system and the optimal design of its components (pipes, pumping stations and storage reservoirs) are greatly simplified.

The development of WTRNet aimed at incorporating both the process synthesis and water distribution aspects of reuse schemes in an integrated DSS, and overcoming some of the limitations that appear in currently available decision support tools. Some specific objectives set out in the development of the software were:

- Provide a completely open modelling environment that will allow users flexibility in terms of editing and adding information to the software knowledge base (e.g. unit processes and their characteristics, pollutants to be considered, use types and quality requirements, rules for combining unit processes in a treatment train, etc.),
- Provide suggestions for complete treatment trains based on the influent quality (or current level of treatment provided in the case of existing wastewater treatment facilities) and qual-

ity requirements for “standard” end uses of reclaimed water,

- Include the distribution system in the reuse scheme evaluation, by allowing users to specify the locations of pumping, transmission and storage facilities and providing a least-cost preliminary sizing of the distribution system that meets all operational requirements.

The software includes a knowledge base, a control module which contains the graphical user interface (GUI), and three computational modules for evaluation of treatment performance, sizing of the distribution system and optimisation. Each of these components is described briefly below, while additional details can be found in [17].

3.1. Knowledge base

The knowledge base contains the following information: water quality requirements for different types of end uses of reclaimed water, design and costing information on unit processes, suggestions for treatment trains that could be used for influent quality/end use combinations, rules for combining unit processes, and the design and costing information for the distribution system components. There are 44 unit processes currently included in the knowledge base, ranging from preliminary treatment to disinfection, as listed in Table 1. For each of the unit processes, the following information was assembled: maximum allowable influent pollutant concentrations, design criteria for sizing, process efficiencies for a series of pollutants, land and labour requirements, sludge and concentrates production, cost estimates and preference scores on qualitative evaluation criteria. All of this information is displayed to the user in a series of editable forms, which allow the user to review all the information and alter the expressions used in the calculation to suit local conditions. Further details on the information contained in the knowledge base can be found in [17].

3.2. Treatment performance module

The treatment performance has been developed with functionality to perform the evaluation of user-selected combinations of unit processes in a treatment train. The evaluation of treatment train performance and the display of treatment train evaluation results are carried out as changes to the treatment train are made. Since the evaluation results in a large output, the calculated data is displayed through four separate frames on the form: effluent quality, pollutant percent removed, evaluation criteria scores and costs and resources.

3.3. Distribution system sizing module

The distribution system performance computational module is used to optimally size the distribution system elements based on a pre-determined branched layout and preferences of the user for locating the pumping and storage facilities. The method used is a two-step procedure that first determines the optimal allocation of reclaimed water (along with optimal sizes of seasonal storage), followed by the sizing of pipes and pumping stations.

The problem of optimal allocation of reclaimed water is solved as a minimum cost flow problem following an approach similar to the one presented in [18], and solved using the RELAX-IV algorithm [19]. The solution of the minimum cost flow problem determines the flows in real parts of the network (pipes) and conceptual flows (storage carryover arcs) over twelve monthly intervals and fixed locations of storage facilities. Output from this optimization algorithm is used in three ways: 1) the optimal operating policy identifies volumes of reclaimed water transferred to each user, 2) maximum monthly flows in the real part of the network are used to calculate the pipe head losses for the optimal sizing of pipes and pumping stations, and 3) the maximum storage carryover arcs are used to size and cost the seasonal storage elements of the distribution network.

Table 1
Unit processes included in the model knowledge base

Category	Unit processes
Preliminary	Bar screen Grit chamber Coarse screen
Primary	Fine screen Sedimentation w/o coagulant Sedimentation w/ coagulant DAF w/ coagulant Membrane filtration Actiflo®
Secondary	High loaded activated sludge + secondary sedimentation Low loaded activated sludge w/o de-N + secondary sedimentation Low loaded activated sludge w/ de-N + secondary sedimentation Trickling filter + secondary sedimentation RBC Submerged aerated filter Stabilization pond Constructed wetland Membrane bioreactor EBPR P-precipitation
Tertiary	Filtration over fine porous media Surface filtration Micro filtration Ultra filtration Nano filtration Reverse osmosis GAC PAC Ion exchange Advanced oxidation SAT Maturation pond Constructed wetland - polishing Flocculation
Disinfection	Ozone Paracetic acid Chlorine dioxide Chlorine gas UV radiation

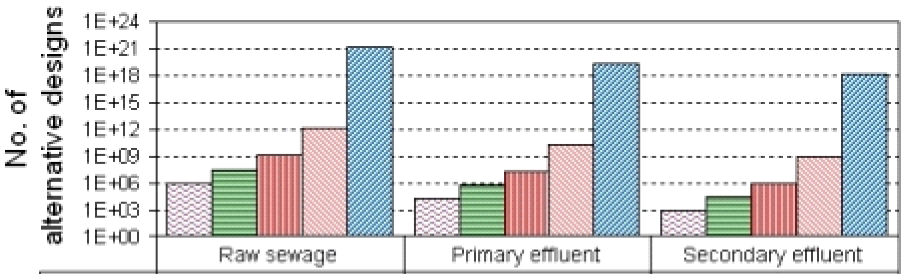
The least-cost sizing of pipes and pumping facilities is then carried out using a linear programming (LP) algorithm, which uses the information on standard pipe sizes and pumping station costs contained in the model knowledge base. The model is limited to branched distribution net-works, typical in water reuse schemes and appropriate at the planning level of analysis, and uses standard representation of the network in the form of links and nodes. Each link is further conceptualized as consisting of a series of segments of standard pipe sizes, where the user selects the sizes they wish to be considered for each of the network links.

3.4. Optimisation module

As indicated above, the knowledge base included in WTRNet covers 44 treatment unit processes. Evaluating all possible combinations of these unit processes (i.e. without any rules for combining them in a meaningful way) yields the number of total possible combinations as 1.76×10^{13}. However, the analyses of water reuse options can be conducted in situations where some treatment of wastewater is already provided. In addition, rules incorporated in WTRNet for assembling treatment trains further restrict the search space.

The combined effect of introducing treatment train rules and restricting the starting unit process according to the influent quality on the possible number of ways in which the unit processes could be combined to form a treatment train was analysed. The results of this analysis, shown in Fig. 1, indicate that the number of possible treatment trains is drastically reduced if treatment train assembly rules are considered. The same figure has additional results showing the number of possible design alternatives for various numbers of potential end-users and influent quality. In the case of raw sewage influent, the total number of design alternatives for any number of end-users requires that a formalised optimisation approach be applied. The situation is similar if primary effluent is used as a source in a system incorporating several potential end-users. If secondary effluent is used as a source and only several potential end-users are considered, an exhaustive search could potentially be used to identify the least-cost alternative.

In order to accommodate the wide range of the number of possible design alternatives, three algorithms are incorporated in the optimisation module. If the secondary effluent is to be reclaimed and the number of potential customers is not large, exhaustive enumeration is used to determine the least-cost design alternatives for all combinations of end-users. If the secondary effluent is to be reclaimed for a (potentially) large number of end-users, a simple genetic algorithm (GA) is used for optimal user selection. Finally, if the source of water is raw sewage or primary



	Raw sewage	Primary effluent	Secondary effluent
▨ 1 user	1.21E+06	19,608	1,139
🟩 5 users	3.74E+07	607,848	35,309
🟥 10 users	1.24E+09	2.01E+07	1.17E+06
▨ 20 users	1.27E+12	2.06E+10	1.19E+09
🟦 50 users	1.36E+21	2.21E+19	1.28E+18

Fig. 1. Number of design alternatives.

effluent, the optimisation algorithm used is a GA with customised operators. The algorithm conducts a simultaneous search of least-cost design alternatives and the best selection of customers, and uses the project net present value (NPV) as the evaluation criteria.

4. Software validation

Results of the validation of the WTRNet software are discussed below. The validation was carried out by comparing its output with values recorded at Wulpen WWTP. In addition, the software evaluation results were compared with values reported in the scientific and technical literature for a theoretical study of process cost estimation and comparison of various wastewater treatment schemes, a full-scale MBR facility, and a demonstration scale MBR/RO facility.

The WWTP Wulpen is a low loaded activated sludge system composed by oxidation ditches preceded by a pre-denitrification step. In order to reduce the extraction of natural groundwater for potable water production and hold back the saline intrusion at the Flemish coast of Belgium, 2,500,000 m^3/y of the plant effluent is infiltrated in the dunes after treatment with Microfiltration (MF), Reverse osmosis (RO) and Ultraviolet (UV) disinfection. The produced RO filtrate is reconditioned to match the natural salt content in the dune water. The recharged water is recaptured after a minimum residence time of 40 days in the dune aquifer.

Concentration of several pollutants measured at WWTP Wulpen was compared with the results obtained from WTRNet simulation software. Overall, the comparison indicated that the software is generally functioning as intended, meaning that the calculations produce a gradual removal of pollutants through each of the unit processes in the treatment train. Concentrations of SS, BOD, and TN in the secondary effluent calculated by the software are generally in good agreement with the measured values in terms of average values. The software indicates a wider range of expected performance of the secondary effluent than what is evident from the measurements. The secondary effluent COD concentrations suggested by the model appeared to be too high, compared with measured data. The assumption made in the software regarding the removal of COD by the Low Loaded AS is that the effluent will contain the soluble inert fraction of the COD, which is typically in the 7–12% range of the raw sewage COD concentration. This results in the prediction of the average effluent quality of 65 mg/L based on the influent COD concentration of 650 mg/L (10% inert soluble COD). The concentration of TN in the MF effluent calculated by the model matches well with measured data, while the model seems to underestimate the additional removal offered by RO. The TP concentration in the secondary effluent predicted by the model seems to be on the optimistic side. The software calculates the quality of the P-precipitation process simply as minimum, average and maximum TP concentrations, and may need to be revised. This also influences the effluent TP concentrations from MF and RO, which appeared to be low compared with measured data.

The detailed treatment train information (process capacities, costs, and other resources) was not available on a unit process basis. Instead, each piece of information that was provided and usable was compared against the values generated by WTRNet. The recovery of the MF was indicated as 87.5%, which compares favourably with the value of 85% contained in the knowledge base. Similarly, the recovery for RO was indicated as 75%, compared to the knowledge base value of 77.5%.

Capital cost of the treatment up to the MF (secondary treatment) was not available, since the system was upgraded recently and only that data was available. Capital costs for MF, RO and UV were provide as a lump sum of €5.5 million, of which €2.5 million was the cost related to construction and the remaining €3 million was electromechanical equipment. The estimated capital cost for these processes by WTRNet was €5.71 million, which compares quite well with the actual capital costs reported. Annual O&M costs for the secondary treatment (i.e. processes up to and including P-precipitation) provided by Aquafin is approximately €1.18 million, while the cost estimated by WTRNet is higher at €1.46 million. A large portion of this is the cost of running the Low Loaded Activated Sludge process (more than €1 million), which is calculated rather crudely in the software as 10% of capital costs, not accounting that economies of scale may exist in the case of a large WWTP such as Wulpen.

Annual sludge production for the secondary treatment (i.e. processes up to and including P-precipitation) reported by Aquafin is 1,582 tons of dry sludge (DS). This did not compare favourably with the WTRNet generated values when average sludge production was used for the Low Loaded Activated Sludge process (65 g DS/PE.d). When this was reduced to a minimum value contained in the knowledge base of 35 g DS/PE.d, the calculated annual sludge production of 1,776 tons was calculated by the model, which is more in line with the observed value.

The unit energy consumption was provided for MF and RO as 0.2 kWh/m³ and 0.6 kWh/m³, respectively. This was compared against the information contained in the knowledge base, which were provided independently and are expressed in same units. The value for MF matches closely with the range of 0.15–0.40 kWh/m³ contained in the knowledge base, as well as the energy consumption reported for RO, which was changed in the knowledge base from 1 kWh/m³ (a value more typical for desalination applications) as a result of the validation.

The first comparison with literature values, conducted using [20] as the source of information, was on a theoretical study of process cost estimation and comparison of various wastewater treatment schemes, based mainly on proprietary software owned by the Zenon company. The comparison regarding costs and energy requirements suggests that reliable estimates are obtained from WTRNet. It is important to mention that the expected accuracy in the available cost figures is ±25%, as reported in [20]. Therefore the performance of WTRNet compared to proprietary software by a company with well known expertise and involvement in (cutting-edge) membrane treatment is encouraging. A significant discrepancy was observed between the land requirement estimates produced by WTRNet and the literature data (which included area required for roads, parking, laboratory, etc.).

The second comparison of model-generated values was conducted using a technical report on an existing MBR process in the city of Cauley Creek, Georgia, USA, for wastewater reclamation and reuse [21,22], which is based on a membrane bioreactor technology. The plant process includes fine screening, vortex grit removal, biological treatment using anoxic and aerobic zones, filtration through a membrane bioreactor and ultraviolet (UV) disinfection. The process also includes chemical phosphorus removal and alkalinity addition. It was observed that the unit product O&M cost estimate of WTRNet is very close to real plant data. In this comparison, the cost of chemicals for alkalinity addition and chemical phosphorus removal was added to the figures obtained by WTRNet since no specific provision for their calculation is available in the software. Energy consumption and labour requirement figures are reasonable but somewhat underestimated.

The last technical report used for validation is from a study involving demonstration scale testing of an integrated MBR/RO treatment train to reclaim municipal wastewater in the city of McAllen, Texas, for use as a new drinking water supply [23]. Detailed available capital and O&M cost estimates for a plant with a capacity of 26,000 m³/d of treated water were compared with WTRNet predictions. The O&M cost estimates obtained by WTRNet are very close to the estimates provided by organizations with well known involvement and expertise in water and wastewater treatment. Capital cost estimates are again here reasonable with the exception of the MBR–RO process where the WTRNet estimate is higher. One reason for this discrepancy lies in the estimate for the pre-treatment to the MBR process (i.e. screening, grit removal), where a significant contribution in the cost is predicted by WTRNet (1,700,000 €), whereas the literature data suggest only a minor cost for this part of the process scheme (17,000 €).

5. Case study

The WTRNet software has been applied in the study of industrial water reuse options in the city of Kyjov, located in the South Moravia area of the Czech Republic. The industrial zone of Kyjov is approximately 5 ha in size, within which the majority of businesses are in the metal and glass industries. The wastewater treatment plant (WWTP) in Kyjov, which is in the immediate vicinity of the industrial zone, is sized for approximately 26,000 population equivalents (PE), and currently receives an average flow of 9,500 m³/d. The WWTP is a mechanical-biological treatment plant with aerobic stabilisation of sludge. Collected sewage is pre-treated (bar screen, mechanical fine screen, grit chamber). Another operational complex forms a biological treatment stage, which includes a circulating activation tank, secondary settling tanks, and a pumping station for re-circulated and excess sludge.

Six industries were identified as potential end-users of upgraded wastewater from the Kyjov WWTP. Table 2 displays the details of these industries, along with their estimated quantity requirements for reclaimed water. The total reclaimed water demand estimated for these users represents less than 10% of the current plant average flow. Nevertheless, an assumption was made that 10% of the effluent from the WWTP would need to receive additional treatment in order to satisfy both the quantity and quality requirements of these potential users.

Investigation of wastewater reuse opportunities in Kyjov was carried out using WTRNet. The Kyjov WWTP effluent quantity and quality was used as the source of reclaimed water, and a preliminary layout of the distribution system was implemented. The distribution system modelled consists of a single pumping station and 10,000 m³ of operational storage, both located at the WWTP, in addition to the piping required to deliver the reclaimed water to the potential end-users.

The results of applying the exhaustive enumeration optimisation methodology are shown in Fig. 2. The six potential end-users produced 64 different combinations. For each combination, a least-cost design was produced, comprising the treatment, distribution and total costs indicated in Fig. 2. The first remark that is made on the

Table 2
Potential users of reclaimed water in Kyjov

Company	Industry type	Estimated water demand (m^3/d)
Sebesta spol. s r.o.	Manufacturing of packaged wastewater treatment plants	23
KM Beta a.s.	Manufacturing of building and roofing products	35
Sroubarna Kyjov spol. s r.o	Manufacturing of fasteners	122
EKOR s.r.o	Waste management	9
Mlekarna Kyjov, a.s.	Dairy works	74
Vetropack Moravia Glass a.s	Glass manufacturer	297
Total		600

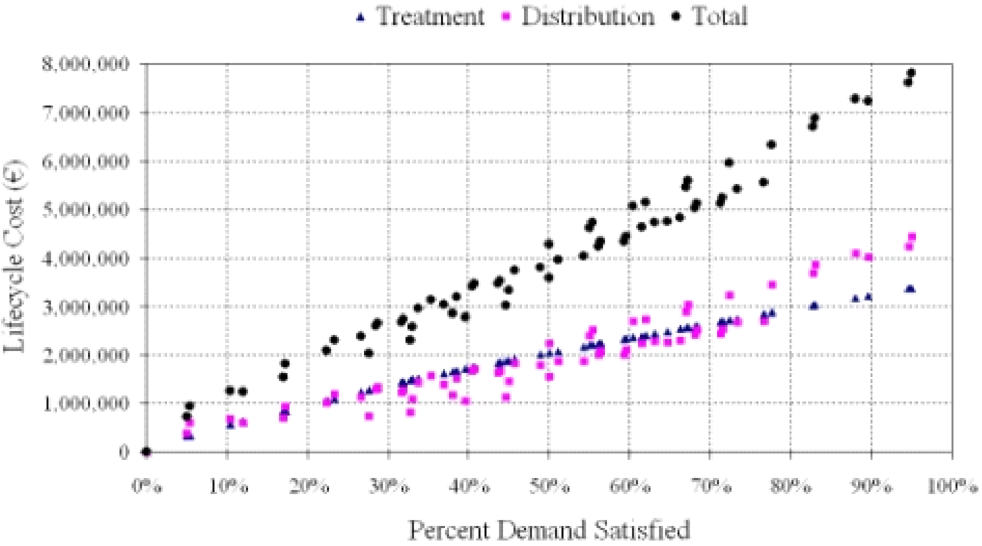


Fig. 2. Results of evaluation of water reuse options in Kyjov.

results of evaluation is that the variability in overall water reclamation system costs is due primarily to the varying costs of the distribution system as different sets of potential end-users were selected. The treatment costs, although not linear, are in proportion to the percent demand satisfied (volume) and do not exhibit such variation, potentially due to the assumption that the potential end-users in this case study require the same quality of water. Nevertheless, the importance of evaluating water reuse systems in an integral manner is clearly demonstrated. Secondly, an examination of the unit processes forming each of the 63 treatment trains was conducted. In close to 70% of the cases, the least-cost treatment train consisted of surface filtration, microfiltration and ion exchange. The remaining treatment trains included combinations of either PAC or surface filtration, followed by nanofiltration. Further examination of results revealed that the most frequently selected treatment train was chosen in cases where up to one-third of total demand was satisfied.

Additional sensitivity analysis was performed to examine the unit process combinations that would be chosen if the demand for reclaimed water was larger (requiring larger treatment facilities). The projected demands for all potential end-users were multiplied, and the least-cost designs were determined for all combinations of end-users as described above. A summary of the selected treatment trains is presented in Table 3, with the overview of selected treatment trains provided in the increasing order of flows. The results indicate that in this particular case study, surface filtration in combination with nano filtration appears attractive only for small flows, while the surface filtration combined with micro filtration and chlorination would be the most likely least-cost option if the demand for reclaimed water was four times larger

The results of evaluations using WTRNet provide a complete set of possible water reuse options in Kyjov for the selected potential end-users. This is in contrast to the traditional approach, where the best out of several alternatives identified a priori is chosen for further investigations. The importance of the approach considered in WTRNet is illustrated in the case of Kyjov, where results indicate that anywhere between 34% and 45% of the demand could be satisfied with the

Table 3
Sensitivity analysis of least-cost treatment trains

Percentage of projected demand	Overview of selected least-cost treatment trains
100%	2% — PAC, nanofiltration 29% — surface filtration, nanofiltration 69% — surface filtration, microfiltration, ion exchange
200%	2% — PAC, nanofiltration 8% — surface filtration, nanofiltration 45% — surface filtration, microfiltration, ion exchange 45% — surface filtration, microfiltration, chlorine dioxide
300%	5% — surface filtration, nanofiltration 26% — surface filtration, microfitration, ion exchange 69% — surface filtration, microfiltration, chlorine dioxide
400%	5% — surface filtration, nanofiltration 10% —surface filtration, microfiltration, ion exchange 85% — surface filtration, microfiltration, chlorine dioxide

same lifecycle cost of €3 million, depending on the choice of end-users. By providing a full range of design alternatives, it is ensured that the decision made on the future course of action involving a more detailed study is sound.

6. Conclusions

Planning of integrated water reuse systems is a highly complex exercise, which needs to consider the selection of treatment processes required to achieve the desired effluent quality, the distribution system required to deliver the reclaimed water to customers, and the selection from a set of possible end-users with potentially differing quantity and quality requirements. The WTRNet decision support tool presented in this paper provides a platform that can be used to conduct the integrated assessment of water reuse options in an efficient manner.

The application of WTRNet is illustrated in a case study of water reuse options in the city of Kyjov, on a relatively small scale with few potential end-users. The application allowed for the following design principles to be derived by analysing the optimisation results:

- The variability in lifecycle cost of water reuse schemes is a direct result of the distribution system costs, while treatment costs are relatively proportional to the volumes of water treated.
- Costs of distributing reclaimed water can comprise a significant portion of the total scheme lifecycle cost, and have to be included in the evaluation.
- Patterns have been observed in the selection of least-cost treatment trains as a function of both the reclaimed water end use type and the size of the scheme.
- A fixed investment (lifecycle) cost can result in satisfying a relatively wide range of the percentage of projected demands.

The motivation for the development of the design support tool presented here was the fact that a water reuse system is likely to have many possible design options, which are all linked to give multiple interactions and a very large number of design combinations. The developed tool allows efficient exploration of design alternatives to be conducted, which should aid planners in the development of more efficient water reuse schemes.

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