International Environmental Modelling and Software Society (iEMSs)
2012 International Congress on Environmental Modelling and Software
Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany
R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.)
http://www.iemss.org/society/index.php/iemss-2012-proceedings

IEDSS as a Tool for the Integrated Assessment of Conventional and Innovative Wastewater Treatment Technologies for Nutrient Removal

[1,2]Rubén Reif, [2]Manel Garrido-Baserba and [1,2]Manel Poch

[1]Laboratory of Chemical and Environmental Engineering (LEQUIA)
Faculty of Sciences, University of Girona;
Email: ruben.reif@udg.edu

[2]Catalan Institute for Water Research (ICRA)
Scientific and technological Park, University of Girona;
Email: mgarrido@icra.cat; mpoch@icra.cat

Abstract: The Urban Wastewater Treatment Directive 91/271/EEC states that wastewaters from populations higher than 2,000 people equivalent must receive appropriate treatment with the aim of improving the ecological status of the receiving aquatic environment. In this context, 'appropriate treatment' is defined as one that fulfils the quality standards set for the receiving waters. This stricter regulation suggest new dimensions of analysis where the affected environments and socioeconomic criteria, together with the characteristics of the available wastewater treatment technologies are to be taken into account for the design of new facilities and the upgrade of existing ones. Thus, in order to deal with this growing complexity, it becomes necessary to acquire and integrate expertise from diverse disciplines. In this paper, a IEDSSs (Intelligent Environmental Decision Support Systems) has been chosen as the most suitable tool to support the identification of the most appropriate wastewater treatment because it integrates expert knowledge together with analytical tools, encouraging a multidisciplinary approach. This paper shows the use of an IEDSS, built according to a knowledge-based methodology, during the decision-making process of selecting feasible treatments and operational strategies for different scenarios characterized by different wastewater composition (C/N ratio), population size (2,000 or 20,000 population equivalent) and specific users requirements (discharge in river or sensitive area, space availability, fiability, operation simplicity, cost-benefit analysis and the use of innovative technologies). For example, the membrane bioreactor was proposed by the IEDSS for scenarios characterized by low space availability and stricter discharge limits (following the requirements of UWTD for sensitive waters). According to the information compiled in the knowledge-bases, the IEDSS also estimated a complete set of outputs such as overall removal efficiencies (nitrogen, phosphorus, organic matter and solids), total cost, sludge production, space requirements, etc.).

Keywords: IEDSS; Knowledge-based methodology; C/N ratio; Wastewater treatment; population equivalent

1. INTRODUCTION

Human-caused aquatic eutrophication is causing a severe reduction of quality in worldwide water bodies. Anthropogenic inputs of phosphorous and nitrogenous compounds, mainly nitrates and phosphates, which occur from various sources such as land application of fertilizers, livestock and industrial activities, constitute a main driver of the worldwide rise of the eutrophication levels. Emission sources are the untreated sewage and discharged effluents from wastewater treatment plants (WWTPs) after incomplete treatment. Despite the growing number of alternatives, inadequate decisions usually lead to the construction of new facilities characterized by a lack of robustness, high operational and maintenance costs and inefficient nutrient removal, and similar issues have been observed for the retrofit of existing plants (Dominguez et al., 2006) Therefore, the preliminary stage of conceptual design should involve a more complex evaluation methodology with respect to multiple objectives at the same time i.e. environmental, economical, technical, and legal. Additionally, the growing number of treatment technologies which can be implemented for the very same case provides water managers with a variety of alternatives to deal with complex types of wastewaters (Hamouda et al., 2009; Joksimovic et al., 2006). However, innovation degree is usually poor when undertaking the design of new facilities, mainly due to an inefficient knowledge transfer between researchers and water managers. Thus, new tools are needed for the WWTP conceptual design step using integrated assessments methods and comprising exhaustive knowledge from conventional and leading-edge technologies (Hidalgo et al., 2007).

Environmental decision support systems (IEDSS) are computer-based programs designed to deal with complex problems. They constitute an useful tool that assists decision makers in choosing between alternative actions by applying expert knowledge about an environmental domain to arrive at recommendations for the various options, improving the consistency and quality of those decisions (Fox and Das, 2000; Cortés et al., 2001). They are particularly useful when the integration of various fields of expertise is requested (Poch et al., 2004). Previous experiences with IEDSS applied for specific wastewater management scenarios, such as the planning of new facilities for small communities, were considered as successful (Alemany et al., 2005). Therefore, further steps in this field should satisfy a wider number of wastewater scenarios, integrating innovative knowledge, leading-edge technologies and considering performance criteria.

This paper presents the innovative software Novedar_IEDSS, designed to assist in the decision-making process for the optimum selection of treatment technologies and the design of complete process flow diagrams (PFDs) for different wastewater management scenarios, facilitating the implementation of reuse criteria.

2. MATERIALS AND METHODS

2.1. Knowledge-based methodologies (KBM)

The [1]Novedar_IEDSS conducts technical, economic and operation analysis, taking into account social aspects and, even, qualitative data. The software includes several extensive databases (legislation, fully characterization of WWTP-related technologies, etc.) and methodologies such as Multicriteria Decision Analysis (MCDA) (Flores et al., 2008), Life Cycle Analysis (LCA) (Gallego et al., 2008), Cost-Benefit Analysis (CBA) and Environmental-Benefit Analysis (EBA) (Molinos-Senante et al., 2012). A variety of sources were used for the development of the different data bases which comprise knowledge extracted from interviews with experts and bibliography within the Novedar Project (which accounts with the cooperation of 11 research groups, 29 relevant water companies and 14 public entities related to the water management, as well as project related engineers, companies and wastewater treatment authorities). Conventional knowledge

acquisition methods (scientific and technical literature, congress presentations, etc.) were also used.
The core of the KBM is composed of two different knowledge bases (KBs). At this moment 274 unit processes are thoroughly characterized in the specifications knowledge base (S-KB) by a whole range of parameters, and encompassed in six topics: Pretreatment, primary treatment, secondary treatment, tertiary treatment, sludge line and head returns. For each technological process, the following information is assembled:

1) Influent information. This information defines the required incoming water quality for unit processes and determines the level of performance needed for the unit to fulfil its functions within the overall process (e.g., presence of grease and oils, maximum COD, and presence of toxic substances).
2) Effluent information. This information describes the expected water quality following treatment by a unit (e.g., process efficiencies for a series of pollutants and nutrient removal).
3) Impact and subproduct information. This includes information on the range of possible impacts that a WWTP can generate, including social issues (e.g., odours, noises, and visual impact) and environmental impacts (e.g., those determined by life cycle and avoided environmental impact analyses).
4) Operation information. This information informs design issues and describes technical characteristics of the units (e.g., maintenance, process stability, and problem frequency).
5) Cost information. These mathematical equations objectively quantify the main costs of treatment processes (e.g., investment, operation costs, and energy consumption).

The compatibility knowledge base (C-KB) consists of a unidirectional table that establish the type of interaction amongst the units composing the whole PFD. Five types of interactions between units processes are identified (High compatibility, synergy, low compatibility, potential incompatibility and incompatibility. In terms of cost, the most remarkable differences between different facilities lie in the technologies used for secondary treatment. For pretreatment and primary treatment steps, previous research (Comas el at., 2004; Aragon et al., 2011) states that investment and operation and maintenance (O&M) costs for such processes are less relevant compared with those associated with secondary treatment. Such units, together with those belonging to the sludge line (digestors, centrifuges, filter bands…) and tertiary treatments (ozonation, ultraviolet disinfection, nanofiltration…) are also registered in the KBs. Considering that this paper is focused on a concrete step of the decision-making process (selection of technologies for secondary treatment under different scenarios) the functioning of C-KB will not be particularly addressed.

When the user proposes a specific scenario (input data, requirements, desired effluent quality, etc.), the IEDSS elaborates a ranking of the feasible secondary treatment units. It corresponds to the user to select one (normally the one that achieved the highest score) in order to proceed with the PFD design. Moreover, the IEDSS is able to provide the user with a complete set of output data regarding the selected technology. Although these data has to be considered as estimative, it can be used for carrying out comparisons between different treatments, in case the user needs to consider various options. However, this feature indeed constitutes a value-added differentiation of the Novedar IEDSS.

2.2. Case studies selection.

The interest is focused in biological nutrient removal technologies due to its potential to achieve low N and P concentrations (<10 mg/L, <0.1 mg/L). Configurations designed to achieve nutrient removal are based on technologies which incorporates nitrification and denitrification stages (Ludzack-Ettinger, oxidation ditch, SBR, etc.). However, effectiveness of such systems is strongly influenced by the wastewater characteristics. In order to adopt suitable treatment schemes, the C/N ratio of the wastewater is a factor of the upmost importance to enhance pollutants degradation capacity and nutrient removal (Neethling et al., 2005; Mulder, 2003). In this sense, some processes might not be effective with C/N ratio< 5 unless an additional carbon source is provided (postanoxic denitrification), increasing the operational costs. Other strategies might be equally effective, for example, the reduction of the total nitrogen content treating a specific stream such as the head returns. The Urban Wastewater Treatment Directive (UWTD) imposes pollutant limits on all WWTP which operate above/below a qualifying population equivalent (p.e.) and discharging to designated sensitive waters: COD: 125 mg/l; TSS: 35-60 mg/l; Total Phosphorus: 2 mg/l; Total Nitrogen N: 15 mg/l), for p.e.<100,000. These parameters will be used to assess the suitability of the different alternatives for effluent discharge in such areas. With the aim to simulate a typical wastewater composition, several parameters were used as input data (Table 1). Three case studies, based on different C/N ratio and p.e. were assessed with the IEDSS, as shown in Table 1. Cases A and B considered a plant serving a population of 20,000 p.e. and C dealt with a small facility of 2,000 p.e. In the scenario A, the ratio was set at an optimum value of 8, whereas B and C considered low (5) and high (20) values respectively.

Table 1. Scenario selection according to different influent characteristics

Input Data	Scenario A	Scenario B	Scenario C
Population equivalent	20,000	20,000	2,000
Flow-rate ($m^3 \cdot d^{-1}$)	4,000	4,000	400
Chemical Oxygen Demand ($mg \cdot L^{-1}$)	400	300	500
Total Nitrogen ($mg \cdot L^{-1}$)	50	60	25
C/N Ratio	8	5	20
Total Phosphorus ($mg \cdot L^{-1}$)	8	8	8
Total Suspended Solids ($mg \cdot L^{-1}$)	80	80	80

3. RESULTS AND DISCUSSION

3.1. Case study A: Optimum C/N ratio

6 restrictions or user requirements were randomly introduced at the data entry stage, thus generating 6 subcases for each scenario as shown in Table 2. When the first restriction (discharge in sensitive area) is selected, only those secondary treatment units able to remove nutrients at a significant extent will be proposed. On the contrary, the other 5 restrictions (cost optimization, operation simplicity, space constraints, fiability and innovation degree) do not exclude any treatment, but influence the ranking of the proposed technologies following a MCDA methodology: the weighed sum model (Chowdhury et al., 2008). According to the methodology built within the IEDSS, it is possible to assign a different weight or relevance to each restriction (for example, 75% cost optimization and 25% fiability). With this information, the IEDSS will score and rank the feasible treatments. If we change the criteria or the weight, the final score (and consequently, the position in the ranking) will be accordingly modified. This feature is crucial, particularly when three or more different criteria are applied simultaneously. In the subcases considered in this paper, we assigned a similar weight for each requirement (for example, A2: 50% cost optimization and 50% operation simplicity). When the user only introduces the input data from Table 1 without any restriction, the IEDSS will randomly propose treatment alternatives compatible with the wastewater characteristics and population size.

Restrictions considered for scenarios B and C were similar to the ones applied in A. For example, the subcase B3 consists of the selection of units suitable for treating wastewater at low C/N ratio, under the requirements of cost optimization (33.3%), low space availability (33.3%) and high innovation degree (33.3%).

Table 2. Restrictions considered in the decision-making process for scenario A (also valid for B and C)

	A1	A2	A3	A4	A5	A6
Discharge in sensitive area				**x**	**x**	**x**
Cost optimization		**x**	**x**		**x**	
Operation simplicity		**x**				**x**
Space constraints	**x**		**x**	**x**		
Fiability			**x**			**x**
Innovation degree				**x**		

Table 3 shows the treatments that achieved the highest score for subcases A1 to A6. After the user selects a specific treatment (normally the first one in the ranking), the IEDSS will provide the user with a set of output data and operational parameters/strategies (for example, typical ranges of hydraulic sludge retention time) as shown in Table 3. A membrane bioreactor (MBR) was the selection in case A1 (space constraints), tied in the ranking with SBRs. Nitrogen elimination was not pursued in A1 and according to the output data, removal of N and P was low. MBRs (and many other treatments) can be operated for N removal, although the IEDSS estimated the output data for this scenario based only on operational criteria for elimination of organic matter, solids, pathogens and population size.
In case A2, when cost optimization and simplicity were required, a conventional activated sludge system (CAS) was the most favoured option. Although the same treatment, sequencing batch reactor (SBR), was proposed for cases A3 and A4, it is important to highlight the differences in the output data provided by the IEDSS in both subcases. In A4, effluent quality must comply with UWTD requirements and the selection must prioritize the use of innovative technologies. In this situation, the IEDSS proposes a SBR upgraded to nutrients removal. In case the user needs further information regarding SBR operation to eliminate nutrients, it is possible to access to a general database to find scientific references from journals or expertise knowledge. For example, in this case the IEDSS shows information from the work of Puig et al., (2007) (the use of anaerobic–anoxic–aerobic phases with multiple feeding events over one cycle). Finally, the solution for A5 was an oxidation ditch operated for nutrients removal (lower cost) and, on the contrary, the extended aeration process was the solution for A6, due to its high simplicity.

Table 3. Secondary treatment selection and DSS outputs for case A

		Effluent characteristics (mg L^{-1})							
	Selected treatment	Total N	Total P	TSS	COD	Cost (M€)	Sludge (kg d^{-1})	Space (m^2)	Score
A1	MBR	40	2.4	3.2	41.4	7.12	1365	20,000	10
A2	CAS	22	2.4	2	35	6.36	873.6	32,120	4.6
A3	SBR	40	2.4	3.2	41.4	5.93	1365	20,000	5.4
A4	SBR (N/P removal)	1	0.5	3.2	33.12	7.38	1201.2	20,000	10
A5	Oxidation ditch	5	2	1.5	23.04	5.22	1201.2	30,125	6.3
A6	Extended aeration	5	1.8	1.5	23.04	7.4	1365	35,125	4

3.2. Case study B: Low C/N ratio

As can be observed in Table 4, technologies proposed by the IEDSS for B1- B3 are similar to A1-A3. The explanation is simple: the ratio is not an influencing factor in the decision-making process when the removal of nutrients is not requested. In the remaining cases (A4-A6), the IEDSS proposed additional strategies in order to adjust the ratio: the innovative annamox process for the treatment of head returns or the addition of external carbon sources (for example, methanol). Van Dongen et al., (2001) estimated an operation cost for the annamox process of 0.22 €/Kg N, substantially lower than the price of methanol (0.75 €/Kg N). However, methanol addition is indeed a more simple and reliable operational strategy. The recommendation of one strategy or the other will depend again on the requirements set by the user. Regarding phosphorus elimination, $FeCl_3$ addition was the option recommended by the IEDSS in the studied situations. However, the database also contains exhaustive information regarding enhanced biological phosphorus removal systems, which might have been proposed as well.
A MBR was again suggested for case B4 (low space requirements). When the user required increased simplicity and fiability (B6), the Ludzack-Ettinger process was the option proposed whereas an oxidation ditch was selected for costs optimization in B5.

Table 4. Secondary treatment selection and DSS outputs for case B (low C/N ratio)

		Effluent characteristics (mg L^{-1})							
	Selected treatment	Total N	Total P	TSS	COD	Cost (M€)	Sludge (Kg d^{-1})	Space (m^2)	Score
B1	SBR	47	2.4	3.2	33.1	5.93	1365	20,000	10
B2	CAS	25	2.4	2	30	6.36	873.6	15,125	4.6
B3	SBR	47	2.4	3.2	33.1	5.93	1365	20,000	5.4
B4	MBR + Annamox + FeCl3	1.5	1.5	0.1	25.9	7.62	1528.8	21,225	8.8
B5	Oxidation Ditch + MeOH+ FeCl3	6	1.7	2	31	5.22	1201.2	30.125	6.3
B6	Ludzack-Ettinger + MeOH + FeCl3	1.2	2	1.82	31	7.38	971.88	35.000	5

3.3. Case study C: High C/N ratio and small facility

The design of treatment facilities used in medium and large cities do not give satisfactory results when they are implanted directly into small agglomerations (unaffordable operation and maintenance costs). Such designs should rely on consolidated or more innovative technologies that allow flexible operation, fiability and low O&M costs, achieving sufficient effluent quality (Eusebi et al., 2008). In this sense, the use of an IEDSS containing expert knowledge for the design of small facilities is of particular interest for decision-makers. Therefore, the main goal of this section is to show how the IEDSS addresses the selection of specific units for small wastewater treatment plants (Table 5). This feature is possible since the information compiled in S-KB also includes detailed descriptions of technologies particularly appropriate for the design of small facilities. Regarding the ratio, this scenario does not constitute a major challenge in order to comply with discharge limits due to the low nitrogen concentration in sewage.

Table 5. Secondary treatment selection and DSS outputs for case C (high C/N ratio and small facility)

		Effluent characteristics (mg L^{-1})							
	Selected treatment	Total N	Total P	TSS	COD	Cost (M€)	Sludge (Kg d^{-1})	Space (m^2)	Score
C1	ISF	14	6.2	0.3	39.1	0.13	152	430	9.8
C2	MBBR	12	5.6	8	75	1.64	45.5	812	5.5
C3	Tricking Filter	16.3	5.2	2.9	32.3	1.59	54.6	694	4.6
C4	AnoxAn	6.5	1	2.4	60	-	-	-	8
C5	ISF + FeCl3	9	1.5	0.3	39.1	0.13	152	430	9.8
C6	CW + FeCl3	7.5	2	2.2	43.8	1.44	-	14,490	7.5

Substantially different technologies were selected in this scenario, as can be observed in Table 5. More concretely, extensive and intensive treatment units such as intermittent sand filter (ISF) (low space), moving bed biofilm reactor (MBBR) (cheaper and easy to operate), trickling filter (reliable and cost-effective) or constructed wetlands (CW) (simple and reliable). The AnoxAn bioreactor system was proposed in C4. It is an innovative technology which combines treatment at different redox conditions and clarification within the same unit, being adequate to produce effluents suitable for discharge in sensitive areas with no additional carbon source or phosphorus precipitation. However, a major drawback for AnoxAn implementation is the lack of experimental data from full-scale facilities. Therefore, this option is only displayed according to specific user requirements. In order to enhance phosphorus removal, the addition of $FeCl_3$ was again proposed by the IEDSS to comply with discharge limits in C5 and C6.

4. CONCLUSIONS

The design of integrated wastewater treatment plants is a complex exercise that must consider a wide range of objectives in order to select feasible combinations of treatment processes to achieve a desired effluent quality. The IEDSS presented in this work constitutes a further step in the integration of various aspects of wastewater management. The incorporation of multi-criteria decision methods in the evaluation of treatment units enabled to embrace an integrated and comprehensive analysis of several parameters and indicators (e.g., environmental, economic and technical). Therefore, the proposed approach efficiently explores different alternatives, which should contribute to the development of more efficient and environmentally friendly WWTPs.

A specific case study, the treatment of wastewater at different C/N ratios was assessed, showing different proposals for secondary treatment units. Different selection criteria were: size of the facility (2,000 or 20,000 peq), fate of treated effluent (river or sensible area discharge), the use of innovative technologies, simplicity, cost optimization, fiability and space constraints. Based on the combination of these criteria, the IEDSS was able to propose different alternatives providing the user with specific operational strategies for ratio adjustment in some cases. When the C/N ratio was set in the range of 8-9, optimum to achieve a high degree of nitrogen removal, the IEDSS selected a sequencing batch reactor in three examples due to its flexibility and low space requirements. When the ratio was not optimum (5), technologies suitable for nitrogen removal were selected. Methanol addition (more reliable and simple) or the annamox process (less expensive) was suggested as additional strategies for ratio adjustment. In a third case study (high C/N ratio), the main objective was to search for units suitable for small-sized wastewater treatment plants. In this case, the IEDSS proposed the use of constructed wetlands, moving bed biofilm reactors or tricking filters. An

innovative process under pilot-scale development, the AnoxAn process was also proposed in one specific case.
The adoption of the IEDSS methodology for these scenarios constitutes a highlight for decision makers, since it embraces a variety of different criteria, offering several technological alternatives adapted for each specific situation.

ACKNOWLEDGMENTS

The authors would like to thank the financial support from the Spanish Ministry of Science and Innovation (NOVEDAR CONSOLIDER CDS2007-00055) and our computer engineering collaborators Adrià Riu, Raül Clemente and Albert Benzal for their helpful support and suggestions.

REFERENCES

Alemany, J., Comas, J., Turon, C., Balaguer, M. D., Poch, M., Puig, M. A., and Bou, J., Evaluating the application of a decision support system in identifying adequate wastewater treatment for small communities. A case study: The Fluvia River Basin, *Water Science and Technology*, 51(10), 179-186, 2005.

Aragón, A., Salas, J.J., Ortega, E., and Ferrer, Y., Lacks and needs of R&D on wastewater treatment in small populations, *Water Practice & Technology*, doi:10.2166/wpt.2011.030, 2011.

Chowdhury R.K., and Rahman R., Multicriteria decision analysis in water resources management: The malnichara channel improvement, *International Journal of Environmental Science and Technology* 5(2), 195-204, 2008.

Comas, J., Alemany, J., Poch, M., Torrens, A., Salgot, M., and Bou, J., Development of a knowledge-based decision support system for identifying adequate wastewater treatment for small communities. *Water Science and Technology,* 48 (11-12), 393-400, 2004.

Cortés, U., Sànchez-Marrè, M., Sangüesa, R., Comas, J., R-Roda, I., Poch, M., and Riaño, D., Knowledge Management in Environmental Decision Support Systems, *The European Journal on Artificial Intelligence*, 14(1),3-12, 2001.

Dominguez, D., and Gujer, W., Evolution of a wastewater treatment plant challenges traditional design concepts, *Water Research*, 40(7), 1389-1396, 2006.

Eusebi, A.L., Carletti, G., Cola, E., Fatone, F., and Battistoni, P., Switching small WWTPs from extended to intermittent aeration: process behaviour and performances, *Water Science and Technology*, 58 (4), 865-872, 2008.

Flores-Alsina, X., Rodríguez-Roda, I., Sin, G., and Gernaey, K.V., Multi-criteria evaluation of wastewater treatment plant control strategies under uncertainty. Water Research, 42 (17), 4485-4497, (2008).

Fox, J., and Das, S., Safe and Sound: Artificial Intelligence in Hazardous Applications, AAAI and MIT Press, 2000.

Gallego, A., Hospido, A., Moreira, M.T., and Feijoo, G., Environmental performance of wastewater treatment plants for small populations. *Resources, Conservation and Recycling*, 52, 931-40, 2008.

Garrido-Baserba, M., Reif, R., Rodríguez-Roda, I., and Poch, M., A knowledge management methodology for the integrated assessment of WWTP configurations during conceptual design. *Water Science and Technology*. In press, 2012.

Hamouda, M.A., Anderson, W.B., and Huck, P.M., Decision support systems in water and wastewater treatment process selection and design: A review. *Water Science and Technology*. 60 (7), 1767-1770, 2009.

Hidalgo, D., Irusta, R., Martinez, L., Fatta, D., and Papadopoulos, A., Development of a multi-function software decision support tool for the promotion of the safe reuse of treated urban wastewater. *Desalination*, 215 (1-3), 90-103, 2007.

Joksimovic, D., Savic, D.A., and Walters, G.A., An integrated approach to least-cost planning of water reuse schemes. *Water Science and Technology: Water Supply*. 6 (5), 93-100, 2006.

Molinos-Senante, M., Garrido-Baserba, M., Reif, R., Hernandez, F., and Poch, M., Optimization of wastewater treatment plant design for small communities: environmental and economic aspects. *Science of the Total Environment* (2012). *In press*

Mulder, A., The quest for sustainable nitrogen removal technologies, *Water Science and Technology, 48(1), 67-75, 2003.*

Neethling, J.B., Bakke, B., Benisch, M., Gu, A., Stephens, H., Stensel, H.D., and Moore, R., Factors Influencing the Reliability of Enhanced Biological Phosphorus Removal, *Water Environment Research Foundation, Alexandria, USA,* 2005.

Poch, M., Comas, J., Rodríguez-Roda, I., Sànchez-Marrè, M., and Cortés, U., Designing and building real environmental decision support systems. *Environmental Modelling and Software*. 19 (9), 857-873, 2004.

Puig, S., Corominas, Ll., Balaguer, M. D., and Colprim, J., Biological nutrient removal by applying SBR technology in small wastewater treatment plants: carbon source and C/N/P ratio effects. *Water Science and Technology*, 55 (7), 135- 141, 2007.

Van Dongen, U., Jetten, M.S.M., and van Loosdrecht, M.C.M., The SHARON-Annamox process for treatment of ammonium rich wastewater. *Water Science and Technology*, 44, 153-160, 2001.