Combined immission-emission based evaluation of integrated urban wastewater system scenarios

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ABSTRACT

This paper fits within the context of the implementation of the EU Water Framework Directive (WFD) and its emission-immission based approach for river basin management. More particularly, it focuses on the sewer-wastewater treatment-river system. Using an integrated model of various system configurations of a real case study, a scenario analysis is performed by evaluating simulation results according to a wide range of hydrological and biochemical criteria. The paper focuses on the selected criteria and proposes an evaluation matrix as a compact way to represent simulation results. It also contains an in-depth discussion on the interpretation of the results, which illustrate the impact of the urban catchment on the receiving river.

KEYWORDS
Integrated urban wastewater system; modelling; scenario evaluation; river water quality criteria

INTRODUCTION
One overall objective of the EU Water Framework Directive (WFD) (CEC, 2000) is to obtain good chemical and ecological status of surface waters. It adopts an emission-immission based approach for river basin management and recognises modelling of systems as one of the tools for good implementation (a.o. Dorge and Windolf (2003), Rekolainen *et al.* (2003)). Together with interdisciplinary collaboration and new technologies, a wide range of models, from river basin models to treatment process models to socio-economic models, can help to identify optimal, tailor-made solutions. Indeed, without interpreting outputs as accurate predictions, the objective of models, in this context, should be to help understand the direction and the magnitude of the optimisation by different options (Jakeman and Letcher (2003)).
With the immission approach, rivers will have to be included explicitly in the evaluation and decision processes, and therefore also in the models. Indeed, every receiving water has its own physical, chemical and biological properties and must therefore be evaluated individually with respect to the effluents of the urban catchment. This asks for a coupled operation of the sewer and the WWTP, guided by what is best for the river water quality (e.g. Vanrolleghem *et al.* (1996), Rauch *et al.* (1998)).

Models are applied in view of various goals. An integrated model can be used to test scenarios in order to evaluate future impacts e.g. future housing construction or increase of drained impervious surfaces, or to assess certain measures intended to improve performance of the system, e.g. treatment volume increase at the wastewater treatment plant (WWTP) or in-stream aeration of the river (e.g. Frehmann *et al.*. (2002), Vandenberghe and Vanrolleghem (2005)). Benedetti and Vanrolleghem (2007) use integrated models for planning of the WWTP. Other applications include evaluation of operating strategies (e.g. Erbe *et al.*. (2002)) like influent load increase to the WWTP or even implementation of immission-based real-time-control (RTC) (e.g. Meirlaen *et al.*. (2002)).
The WFD implementation should be seen as an opportunity to support developments in the field of urban water management and of tools for assessing river water quality. Using an integrated model of various system configurations of a real case study, a scenario analysis is performed by evaluating long-term dynamic simulation results according to selected hydrological and biochemical criteria. Given the enormous amount of data that is generated by the long-term dynamic simulations of the different scenarios, it is essential to develop a general method that allows for straightforward interpretation of these simulation results towards conclusions on the impact of various system (re)configurations. The method should be easily applicable to different case studies and the chosen evaluation criteria should be suitable in the context of the WFD implementation. The paper focuses on this evaluation method and discusses some of the results.

METHODS AND METHODOLOGY

The 'Bleesbruck' case study

The case study is situated in the lower northern part of Luxembourg and consists of a semi-rural sewer catchment (~ 52,000 population equivalent) drained into one treatment plant and discharging into 3 receiving waters (flows between 2 and 20m^3/s depending on river and season) with differing water quality (see Solvi *et al.* (2005) and Solvi (2007) for more information).

The integrated model

The entire sewer-WWTP-river model was implemented in the WEST® simulation software (MOSTforWATER nv, Belgium) (Vanhooren *et al.*, 2003). For the sewer catchment and network, an extended version of the KOSIM model (ITWH, 2000) was implemented (Solvi *et al.*, 2005), allowing for simulation of backwater effects and first flush phenomena due to pollutant accumulation and wash-off on the surface. For bio-chemical reactions in the system, a simplified version of the IWA RWQM1 river water quality model (Reichert *et al.*, 2001) and the IWA ASM2d activated sludge model (Henze *et al.*, 2000) were used. These sub-models were connected by means of interface models (Vanrolleghem *et al.*, 2005), which transform the state variables of one sub-model into the state variables of the following sub-model.
It was sought that all of the sub-models were calibrated over the longest time period possible as long-term analysis is planned in the subsequent scenario analysis. Hence, both the sewer and the WWTP were calibrated for 8 months. Two targeted integrated measurement campaigns were performed, but, unfortunately, only two times two weeks of measurements were available for the river system (spring and autumn).

Scenarios development

From a deficit analysis, it appeared (i) that one of the rivers ('Alzette') brings a large background pollution load from upstream the Bleesbruck catchment, (ii) that the WWTP has poor nitrification capacity and (iii) that the sewer system is overflowing regularly. With the calibrated integrated model and the information on the case study deficits, 15 scenarios were developed (see Table 1). They ranged from source control, to construction measures, to operation schemes or even measures taken in the river. They are described in detail in Solvi (2007).

Table 1. List of simulated scenarios with acronyms for later reference and short description.

Domain	Acronyms	Description
References	**Ref**	Current situation
	None	No urban catchment (only river model)
Source Control	**FlatDWF**	Buffer tanks at housing level to flatten dry weather flow
	FlatNH	Urine separation and buffer tanks to flatten ammonium concentrations
	ImpRed	Impervious surface reduction by decoupling from sewer network (-25%)
	RedInf	Mean infiltration reduction by sewer rehabilitation (-50%)
Construction	**RetBas**	Retention basin construction (Total: 4500m^3)
	SluBu	Construction of incoming sludge buffer tank (100m^3)
	SluWT	SHARON-Anammox treatment of reject water at the WWTP
	NitVol	Increase (x2) of nitrification volume
Operation	**OvLo**	Increase of maximum allowed WWTP hydraulic load (+33%)
	ImprN	Ammonia nitrogen cascade control of aeration
	ImprP	Improved phosphorus control by chemical addition
River measures	**Sha**	Tree plantation along river banks (-33% solar radiation)
	Reae	Artificial reaeration in the river

EVALUATION CRITERIA AND METHOD

The complexity of the scenario analysis lies within the selective choice of criteria and the difficult interpretation of results. Indeed, the modeller is given a very large number of possibilities to analyse modelling outcomes and the differences in the scenario simulations with respect to the reference case. The scenario analysis for this case study was to be performed in a combined emission-immission approach as required by the WFD and had two purposes:

- understand effects of the tested measures within the integrated system,
- identify the appropriateness and implementation feasibility of certain scenarios.

Criteria and thresholds for the Bleesbruck case study

For emissions, the following thresholds were chosen according to the Urban Wastewater Directive (CEC, 1991) for a WWTP having capacities between 10'000 and 100'000 PE: *Total COD<125mg/l*, *TN<15mg/l* and *TP<2mg/l*. As the Bleesbruck treatment plant does not comply with TN emission standards for most of the time, total ammonia (TNH) has been added as criterion with the same limit of 15 mg/l. For emissions from the CSO structures, water volumes, duration and frequency, as well as particulate COD, ammonium and orthophosphate loads were chosen. For all of these variables also mean and maxima were considered.

For immission-based evaluation, *dissolved oxygen, total ammonium, orthophosphate and total COD* were selected. In this study for a lowland river, a DO threshold of 5 mg/l was chosen, which constitutes a good average value for occurring fish species (FWR, 1998).
Ammonium and phosphorus are both nutrients for algae and, in case of too high concentrations, can lead to eutrophication. The excess algae growth can impact on water quality directly (e.g. unsightly scums, clogging of the water course…) or indirectly by exacerbating other problems (e.g. oxygen depletion, ammonia toxicity, loss of submerged aquatic vegetation due to the shading, ...) (Chapra, 1997). Total ammonium (TNH) is contained in the river under ionised and unionised form (NH_4^+ and NH_3), but only the latter is toxic for fish. From the UPM manual (FWR, 1998), Table 2 indicates frequency and duration for un-ionised ammonium thresholds that should not be exceeded. The amount of available NH_3 can be derived from TNH using temperature and pH.

Table 2. Fundamental intermittent standards for un-ionised ammonia concentration (mgN/l)/duration thresholds not to be breached more frequently than shown for an ecosystem suitable of cyprinid fishery (FWR, 1998).

Return period	1 hour	6 hours	24 hours
1 month	0.150	0.075	0.030
3 months	0.225	0.125	0.050
1 year	0.250	0.150	0.065

Both TN and TP can be the limiting factor to algae growth. A rough rule of thumb for assessing which nutrient is limiting, relates to the nitrogen-to-phosphorus ratio (Borchardt, 1996). Ambient TN:TP ratios larger than 20:1 are considered phosphorus limited, and ratios smaller than 10:1 N-limited. In the case of the Bleesbruck rivers, the ratio is above 20 and therefore phosphorus seems to be the limiting nutrient. It should hence be reduced as much as possible and the threshold for duration and frequency calculations was set to be 0.4mg/l.
Total COD is used as another criterion indicating pollution. It represents organic matter whose decomposition might also lead to oxygen depletion and toxicants preferentially associate with it (Chapra, 1997).

The evaluation matrix

The aim of the here developed evaluation method was to obtain a way for easy interpretation of simulation results. Through the abundance of data in terms of time and locations, overview on essential, objective driven outcomes is quickly lost.
The here developed *evaluation matrix* for *long-term assessment* of simulation results contains all the information for scenarios and criteria (see Figure 1). *Locations* for performance evaluation are interfaces, i.e. CSOs and the WWTP, and several locations in the river model. As already mentioned, within the context of the WFD implementation, *immission* concentrations as well as *emission* loads and concentrations are compared to the reference scenario. Chosen quality related *variables* and related *thresholds* will depend on legislative criteria, or, in the river, on toxicity for fish etc.
To get an idea of the overall performance of a chosen scenario over a whole simulation period of 8 months, the following *criteria* for variables were chosen (see Figure 1): means, maxima and minima concentrations in mg/l, exceedance durations D in days (i.e. the time spent above or below certain concentration thresholds) and the number of exceedances F (i.e. how often the concentration threshold is exceeded over the simulation period). The numerical value after letters D and F gives indication of the respective variable's threshold (denoted by '*thr*' in the table). Emission loads of variables are given in tons.

	Variable 1					Variable 2					…	
Emission	Load	Mean	Max	D*thr*	F*thr*	Load	Mean	Max	D*thr*	F*thr*	…	…
Max												
Min												
Ref												
Scenario 1			0.85			0.81	0.81	0.91	0.78	0.83		
Scenario 2			0.94			0.92	0.89	0.95	0.93	1.06		
…												

Figure 1. Example of the evaluation matrix at some location within the integrated system.

Relative values of all the above named criteria are calculated for each scenario by dividing with the value obtained from the reference case, i.e. the integrated system as it exists now. A colour scheme is applied to these results to allow for visual evaluation of scenarios. To account for uncertainties and eliminate possible evaluation of differences that originate from numerical inaccuracies during simulation runs, cells containing relative values in the range 0.95<x<1.05 are shaded in grey (and their values are omitted from the table). To mark improvement between 5 and 15%, the concerned cells are shaded in a light grey. More important amelioration, i.e. >15%, is indicated by a white cell. Negative influence from the measure will colour the cell in black. Hence, as an example, if a measure provokes a considerable increase of the TNH concentration in the river and the relative value goes above 1.05 the cell is coloured in black. Note however that for DO, the same relative value will produce a light grey cell, as 'more' oxygen in the river means an improvement compared to the reference case.

Above the relative values cell block (see Figure 1), the *absolute values* of the criteria are given for the *reference* scenario, as well as for the maximum and minimum values of the scenarios, so as to get an idea about the order of magnitude for variables and criteria.

Interpretation of the cells needs to be done with care as often the isolated consideration of such a relative value can mislead the overall evaluation of a scenario. For example, the number of exceedances always needs to be considered together with the duration of exceedance: an increased number of exceedances does not necessarily mean that a certain measure has a negative impact. It might just mean that, if the duration above the limit has decreased, the threshold value was crossed more often than in the reference scenario. Another criterion to be interpreted carefully concerns the maxima and minima obtained. One should know that these criteria focus on one single value within the simulation results and the 'extreme event' in the reference scenario might not correspond to the 'extreme event' in the considered scenario. Hence, direct comparison should not be done. Also, while a scenario might reduce peaks in general, it might not be able to reduce the extreme event peaks and this would not be reflected in these maxima and minima.

RESULTS

Not all the results on the Bleesbruck case study scenario analysis can be reported here. A more complete analysis can be found in Solvi (2007). In this paper, the evaluation will focus on immission results downstream the WWTP discharge point. Two scenario analyses using scenarios from Table 1 were performed, one for the ‘As-Is’ situation (SAAI) and one for a hypothetical ‘Future’ situation (SAF, described below). It should be noted that not all single cells in the evaluation matrix that show criteria improvement or degradation for a specific scenario will be commented on, as it was felt that only the most relevant results should be discussed, without loosing the overall picture. Also, no concentration versus time graph will be depicted as it would overload the manuscript. However, in general, it makes sense to inspect simulated concentrations in function of time at different locations in the system. This does not only provide an improved understanding of the system but it also serves to check whether produced results are plausible.

Scenario Analysis "As-Is" (SAAI)

Immission results after the WWTP discharge point are summarised in Figure 2. The cells representing the means for the variables of the **None** scenario (absence of a city) reveal that the possible improvement in the river through measures in the urban catchment or the WWTP is relatively small. Except for ammonium, the proportionally little hydraulic contribution of the WWTP and the CSOs compared to the river flow (< 3%) does not significantly influence the average river concentrations. More importantly, the pollutant base concentrations are already relatively high due to the bad river water quality of the river Alzette upstream the considered catchment. Hence, mixing with the treatment plant's effluent will not have as much effect as in the case of low base pollution concentrations in the river as will be made clear in the next section.

	DO				NH				PO				COD	
Immission	Mean	Min	D5	F5	Mean	Max	D2	F2	Mean	Max	D04	F04	Mean	Max
Max	12.4	6.8	20.5	28	1.40	2.76	29.5	26	0.38	0.65	97.5	50	37.6	65.2
Min	7.9	3.1	0.0	0	0.99	2.56	8.5	5	0.32	0.55	47.4	27	33.1	55.9
Ref	11.5	4.6	4.6	10	1.17	2.72	18.1	16	0.33	0.60	60.8	45	37.5	62.7
None			0.81		0.85	0.95	0.47	0.31		0.90	0.78	0.71		
FlatDWF						0.94	0.77	0.50						
FlatNH							0.89	0.69				1.09		
RedImp								0.94				0.89		
RedInf			0.91				0.83	0.94		1.08	0.92	0.84		
RetBas								1.19						
SluBu														
SluWT							0.77	0.50						
NitVol					0.94		0.69	0.50						
OvLo								1.06				1.07		
ImprN			0.95		0.92		0.67	0.50						
ImprP							0.94					1.11		
Sha	0.69	0.68	4.47	2.80	1.21		1.63	1.63	1.14		1.60	0.60	0.88	0.89
Reae	1.07	1.47	0.00	0.00				1.06						

Figure 2. Evaluation matrix for immission downstream WWTP: Simulation results with DO threshold 5mg/l, NH_4-N threshold 2mg/l, PO_4-P threshold 0.4mg/l.

Looking at DO immission results after the WWTP, the matrix in Figure 2 clearly shows that, only in-stream measures like **Sha** and **Reae** have considerable effect on the river DO concentration. Measured and simulated DO concentrations indicate that the river is in a state of supersaturation, i.e. that oxygen levels mostly stay above saturation concentrations (>8mg/l). Due to the presence of high algae concentrations, DO concentrations can reach more than 12mg/l during the day so that, even at night, concentrations do not often go below a DO concentration that cause fish suffocation. Although costs for implementation of reaeration are relatively high regarding maintenance and operation, the **Reae** scenario considerably increases the minimum DO concentrations, and appears a useful measure in case of high eutrophication and fish suffocation at night. With the **Sha** scenario, average DO concentrations decrease significantly and ammonium as well as phosphorus concentrations increase due to reduced consumption by the lower algae mass present in the river, which is reflected in the calculated mean and maxima COD decrease. Also less ammonium will be nitrified due to decreased transformation rates caused by the temperature drop induced by shading. The minimum DO values have decreased and the time of exceedance (time fraction below the threshold) of minimum DO concentrations has increased. This is an unexpected result as with the reduction of solar radiation and algae mass, day-time DO concentrations were expected to decrease and vice versa at night. However, reducing the algae mass will take away supersaturation, which, at night, prevented DO levels to drop too low in the reference situation. Due to the high input of substrate at the Alzette model boundary, and lower DO concentrations with shading during day, oxygen concentrations can drop below a critical threshold at night due to oxygen consumption by bacteria. It seems that shading is only appropriate in cases where the incoming COD load is small.

With scenarios **RedInf** and **ImprN**, the duration below the DO concentration threshold is hardly affected, and interpretation of these scenario results becomes more speculative. It should be noted however, that the improvement reaches up to 50% of the improvement possible in the case of a complete absence of emissions (**None**). From the emission results, it can be concluded that infiltration reduction will reduce emission loads for every considered component, and is the only scenario reducing COD discharge loads. The improved nitrogen control has the best performance regarding the discharge of ammonium in 4 out of the 5 NH_4-N related emission criteria, suggesting less nitrification and oxygen consumption in the river.

The influence of the WWTP on the immission concentrations is most visible for ammonium. In the river downstream the WWTP discharge point, concentrations of total ammonium can stay above 2 mg/l and can result in toxic unionised ammonium concentrations under certain temperatures and pH conditions. Therefore, although the overall mean concentrations cannot be improved, the shortened time span for which the ammonium levels stay above the thresholds reduces the risks for ammonia toxicity (**FlatDWF**, **FlatNH**, **RedInf**, **SluWT**, **NitVol**, **ImprN**).

Scenario Analysis "Future" (SAF)

The impact of the 15 scenarios was also tested on the considered urban catchment for a future scenario in which the upstream conditions of the river Alzette would have been improved through both implementation of the WFD and emission compliance within the Urban Treatment Directive (CEC (1991)) of WWTPs upstream the 'Bleesbruck' catchment. To this end it was supposed that the river Alzette (high base pollution) has the same 'good' water quality as the current river Sûre. Hence, the integrated model remains unaltered apart from the upstream boundary input data to the Alzette, now identical to the Sûre's input data. Also, the kinetic parameter values of the simplified river water quality model were set back to default parameter values of this receiving river model. To visualise the impact on durations and frequencies above the thresholds for ammonium, the threshold concentration has been set to 0.6 mg/l, as for such ammonium concentrations, under high temperature and pH=8, toxic ammonia levels can be reached. For phosphorus, the threshold was now fixed to 0.3 mg/l.

The matrix in Figure 3 shows immission results in the Sûre, again downstream the WWTP discharge point. The **None** scenario proves in this case that the impact of the urban catchment is considerable, especially for duration and frequency of exceeding the thresholds. In comparison with the matrix in Figure 2, the catchment impact is larger than for SAAI, especially for DO, as for this variable the threshold has been kept the same (5mg/l). Average DO concentrations after the WWTP have sunk from 11.5 in SAAI to 6.6 mg/l in SAF. Although the daily fluctuation in concentrations is not as high anymore as it was for the existing situation, the river is now, due to the lower algae mass and therefore absence of supersaturation, much more vulnerable to DO depleting pollution from the WWTP. Although the duration of DO concentrations below the threshold in the reference scenario has not increased compared to the reference case, such exceedances are now mainly caused by the urban catchment discharges and not by the conditions upstream the catchment (see **None**). Indeed, the river's state of eutrophication assured high DO concentrations during the day when the WWTP is discharging its highest load. Now, with DO concentrations being lower, the 5 mg/l threshold is more easily violated.

Immission	DO				NH				PO				COD	
WWTP	Mean	Min	D5	F5	Mean	Max	D06	F06	Mean	Max	D03	F03	Mean	Max
Max	8.5	6.7	6.1	10	0.32	1.09	10.3	41	0.25	0.45	41.71	33	18.3	48.5
Min	6.5	3.9	0.0	1	0.13	0.27	0.0	2	0.23	0.35	18.96	4	17.3	23.7
Ref	6.6	3.9	4.3	7	0.31	0.96	8.3	40	0.25	0.40	40.04	31	18.2	45.1
None		1.06	0.26	0.14	0.41	0.28	0.00	0.05	0.94	0.87	0.47	0.13		0.53
FlatDWF			0.81		0.87	0.82	0.25	0.43				0.87		
FlatNH3						0.90	0.63	0.68						
RedImp			0.89	0.86			0.87	0.80						0.87
RedInf			0.68	0.57	0.83	1.14	0.71	0.70		1.11	0.83	0.81		
RetBas			0.77	0.71			1.23	0.95		1.08		0.77		
SluBu			0.75	0.71			0.26	0.35			0.93	0.90		
SluWT			0.84	0.86	0.86	0.84		0.90				0.87		
NitVol			0.88		0.77	0.84	0.27	0.40				0.90		
OvLo			0.85	0.86		1.09						0.90		
ImprN			0.58	0.57	0.71	0.85	0.15	0.28				1.06		
ImprP				0.86	0.93	0.93	0.76	0.70			0.89	0.65		
Sha			1.40	1.43			1.06							
Reae	1.28	1.70	0.00	0.29										1.07

Figure 3. Evaluation matrix for immission downstream the WWTP: Simulation results with DO threshold 5mg/l, NH4-N threshold 0.6mg/l, PO4-P threshold 0.3mg/l.

Scenario **OvLo** suggests that even though the WWTP has to treat more water and might therefore discharge higher loads and concentrations, the dissolved oxygen is more affected by the discharges of the combined sewer overflow (CSO) prior to the WWTP. The total emissions from WWTP and CSOs report a 10% reduction in total COD load. **RetBas** reflects a similar result; but the nitrification capacity decreases due to the prolonged higher flows into WWTP. Best performing scenarios in terms of ammonium are **RedInf**, **ImprN** and **NitVol** similar to what was found in SAAI. Scenarios **Sha** and **Reae** show similar but somewhat reduced effects compared to the original set up. From immission results at the CSO locations, the **None** scenario now points to the influence of CSOs on the river, which was not the case in SAAI.

DISCUSSION

Scenario analyses have confirmed that in this case study, investments for implementation of the WFD in a first instance need to be done upstream of the Bleesbruck catchment. In other words an upgrade of the treatment facilities of the city of Luxembourg and others is required. These plants are currently being upgraded, and the results also showed that the adaptation of the 'Bleesbruck' WWTP will be beneficial. The second scenario analysis has shown that once the WFD objectives are reached in the Alzette, the urban catchment and especially the existing WWTP will have a more important impact upon the river's water quality. Especially in terms of ammonium, the river concentrations are more than doubled under this future scenario and reflect the daily effluent pattern of the WWTP effluent. Regarding DO concentrations, the river has become more vulnerable to CSOs and WWTP emissions due to the reduced algae presence and the absence of the induced supersaturation at the time of highest COD discharge into the river. From the simulations it could be deduced that COD peak emissions have a considerable impact on the in-river DO concentrations. Taking into account the present background pollution, the implementation of improved control algorithms for nitrogen and phosphorus removal at the treatment plant leads to good results at relatively low costs and can bring about positive changes with regard to peak reduction or even elimination. Consequently, it can reduce the risk of ammonia fish intoxication and, as

phosphorus is the limiting nutrient for algae growth, decrease algae mass in the vicinity of the WWTP.
From the study, the following approach can be suggested to analyse a river system for which an integrated model is available: A long-term immission-based analysis using scenario simulations should be performed. A synthesis of the results in a grey-scale evaluation matrix provides an excellent overview of the overall situation. Simultaneous consideration of emissions will allow for better understanding of the interactions and impacts. An event-based analysis of a selection of time series data will help to visualise what is behind the matrix.

CONCLUSIONS

Using a dynamic, integrated modelling approach and a proposed evaluation method, various scenarios to improve water quality have been compared. The scenario simulations generated long-term data on many variables, available within and at every interface of the subsystems. This overwhelming amount of information showed another face of what can be called 'complexity' and illustrated how easily one can get lost in interpreting the outcomes. The proposed evaluation matrix is estimated a good way to summarise some of the necessary results for this impact analysis and together with the colour scheme applied to the matrix cells, a good visual appreciation of the simulation outcomes was found. A main observation made during the evaluation of results is that all of the criteria are to be considered together. A reduced mean value does not tell anything about the variation of the considered variable, and an increased frequency does not include any information on the duration above/below thresholds. Therefore the matrix format is very appropriate to concisely deal with all these performance criteria.
Some of the results obtained were predictable, but others were unexpected. The learning process through the analysis, both in terms of the case study and regarding the mechanisms within the integrated urban wastewater system is important. Indeed, inspection of results at various locations not only illustrates the various effects that subsystems have on each other, but also helps understanding dependencies in the changes, hence the interactions described by the models. One should certainly bear in mind that this model has its limits. It was constructed for a scenario analysis focussing on biochemical water quality. Conclusions can not be drawn regarding possible hydraulic impacts of CSOs on river morphology nor can answers be provided regarding the consequences for living organism populations nearby the WWTP discharge. If these issues are considered critical for a case study, different, more appropriate models need to be used.
The outcomes are to be seen as qualitative and not quantitative results, and they are to be evaluated with respect to the reference state. The selected case study was not an ideal case to illustrate the usefulness of an immission-based evaluation of the impact of an urban catchment, as the pollutant background concentrations in the river are high due to the river Alzette's contribution. However, even though the DO concentrations were less affected by the city in this situation, incomplete removal of ammonium at the WWTP leads to concentration changes that can be clearly observed in the river. The second (future) scenario analysis revealed that, in case of a future WFD compliance of the Alzette, emissions of the current catchment have a much more important impact on river water quality. The results have shown that depending on the water quality problem of the river, suitable measures can be identified, either within the catchment, the sewer network, the WWTP or the river.

ACKNOWLEDGEMENT

The results presented in this article have been elaborated in the frame of the EU Project CD4WC, contract no. EVK1-CT-2002-00118. This project is organised within the Energy, Environment and Sustainable Development Programme in the 5th Framework Programme for

Science Research and Technological Development of the European Commission. The author was funded through a 'Bourse-Formation-Recherche' by the Luxembourg's Ministry of Culture, Higher Education and Research and was supported by the CRTE /CRP Henri Tudor (Luxembourg). The support of the SIDEN (Syndicat Intercommunal des Eaux Résiduaires du Nord) is gratefully acknowledged. Peter Vanrolleghem holds the Canada Research Chair in Water Quality Modelling.

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