The HSG Guideline Document for Modelling Integrated Urban Wastewater Systems

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ABSTRACT

The importance of integrated modelling of urban wastewater systems is ever increasing, also due to the European Water Framework Directive. In order to facilitate its practical application, the Central European Simulation Research Group (HSG) has prepared a guideline document, suggesting a seven-step procedure to integrated modelling. Findings of recent research and application projects in Central Europe have been integrated in the guideline. The present paper outlines this guideline document. The full guideline will be made available on the Internet.

KEYWORDS

Integrated modelling, integrated urban wastewater systems, modelling, urban drainage, wastewater treatment plant

INTRODUCTION

An important paradigm shift in the definition of performance indicators for urban wastewater systems has occurred in legislation and practice in recent years. Traditionally, major elements of such systems (sewer system, wastewater treatment plant, and receiving water body) are considered separately, and emission-based criteria form the basis for legislation and standards in many countries. With the implementation of the EU Water Framework Directive (WFD) in 2000, river basin-wide analysis has become an important paradigm in sustainable water resources planning and management. The WFD demands approaches for river basin management, which will also have implications on urban wastewater system management within Europe. For surface waters, as a major receiving ecosystem of urban emissions, a good ecological and chemical status is required.

Thus, traditional engineering planning approaches need to be adapted to address the paradigm shift. The exclusive consideration of combined sewer overflow (CSO) volume, frequencies, and pollution load minimisation, for instance, are no longer adequate objectives, since they do not guarantee the achievement of the desired quality of the receiving water body (Butler and Schütze, 2005). It is generally accepted (in science) that optimal management of the individual components of the urban wastewater system does not necessarily yield optimum performance of the entire system. Therefore, an integrated approach accounting for various sources of pollution and impacts on receiving water bodies is required (Rauch and Harremoës, 1996).

Computer-based simulation models are convenient and generally accepted planning and design tools for urban wastewater systems. Since the first INTERURBA conference (Lijklema *et al.*, 1993), integrated modelling still is a challenging topic in research. The uptake of integrated modelling in engineering practice, however, is still limited. The main bottleneck is the complexity of the overall system that prevents a simple linkage of the existing detailed deterministic models of the individual subsystems and a lack of data, which limits the practical application of these models. In the last few years, however, significant efforts have been made to develop simplified approaches suitable for modelling the integrated urban wastewater system (IUWS) and to improve the availability of data and the identification of model parameters.

The Central European Simulation Research Group (Hochschulsimulationsgruppe – HSG, http://www.hsgsim.org) has developed a guideline document to support the application and further development of integrated models for the assessment of IUWS in research and practice. The guideline covers the aspects of system and problem analysis, identification of relevant system processes and evaluation criteria, model setup and analysis, calibration and validation, scenario analysis and documentation. The guideline follows the idea to implement a demand-driven model setup and application. Detailed information is provided to support the model specification based on a thorough analysis of the objectives applied. A focus is placed on the identification and selection of appropriate modelling approaches and their level of detail. Therefore, an iterative process of model analysis and evaluation during model setup is proposed, following the principle of parsimony.

The complete HSG guideline document consists of a state-of-the-art review on integrated modelling of IUWS, the guideline itself and a case study. The documentation of the case study reflects the practical experiences of the authors and provides detailed information on the application of the guideline. The guideline will be made available to interested professionals on the Internet.

This paper introduces the HSG guideline document. Particular emphasis is made on the structure and contents of the proposed procedure, as this is the essential part of the guideline.

STRUCTURE AND CONTENTS OF THE PROPOSED PROCEDURE

The main part of the guideline provides precise instructions for a systematic set up of integrated models and for the application of these models in the context of scenario analysis. The proposed procedure is divided into six major parts:

(1) **System analysis**
(2) **Processes and criteria**
(3) **Modelling approaches and data**
(4) **Analysis of model and data**
(5) **Model calibration and validation**
(6) **Model application**

An additional seventh step comprises of the continuous documentation during all steps of the procedure. In the following, these steps are discussed briefly. Figure 1 shows a flowchart of the complete procedure including all important steps and interactions.

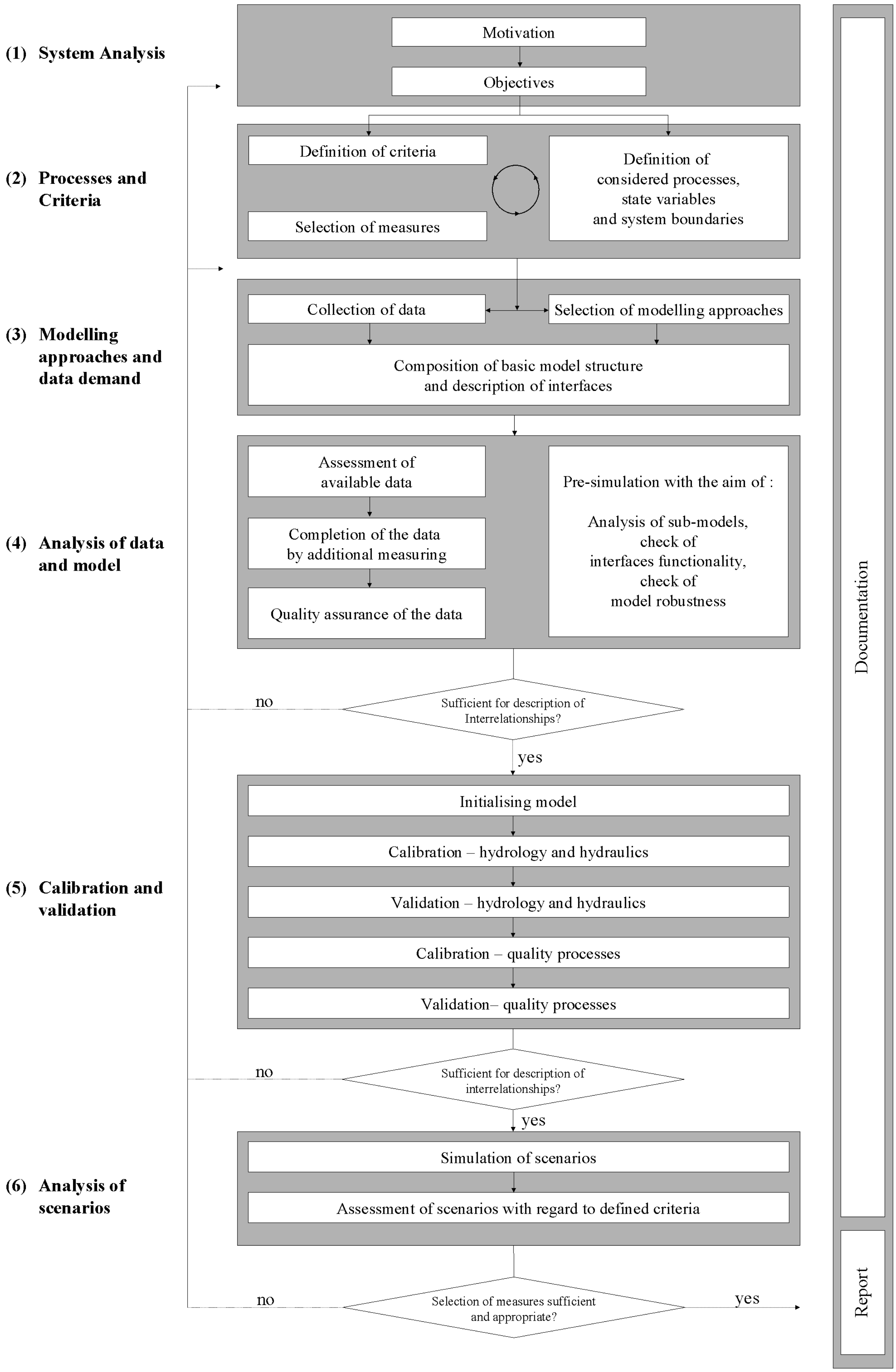

Figure 1. Stepwise approach for integrated modelling according to the HSG guideline

Step 1 - System analysis

Carrying out a simulation study is usually driven by acute, mean- or long-term deficits being observed in the system under consideration. The need for a technical and/or economic system optimisation can be a further reason. Generally, it has to be mentioned that the simulation of such systems in an integrated view results also in a better understanding of the interrelations within the system itself.

The superior objective of a study is directly derived from the motivation and can be formulated in an abstract way (e.g. reduction of artificial indicators like annual overflow volumes and loads or improvement of the water quality in the recipient). A more detailed distinction of the objectives can be deduced from a comparison between the present state of the system (frequently in deficit) and the target state defined.

The present state results from a preliminary system analysis which should be accompanied by an evaluation of the available data. The target state is often determined by legal requirements (external motivation), however, it can also be specified by the system operator's objectives (internal motivation); combinations are also possible. Typically, the analysis process, to be carried out prior to the actual simulation study, is not conducted by the modeller itself. In fact, this task is often accomplished by the system operator, the responsible water authority, or similar superior institutions. This is rather critical, particularly regarding system understanding.

Step 2 - Processes and criteria

In a next step, a more detailed system analysis needs to be carried out. The primary objective of this analysis is the identification of possible causes of negative impacts (deficit analysis) and/or the determination of the optimisation potential of the system as well as the identification of the processes and criteria related to the objectives considered. The identification of relevant state variables (or criteria) and significant processes in the system are in direct connection. In case of legal requirements, compulsory objectives are already defined by established standards. The analysis process is therefore carried out based on these predefined criteria. If no criteria are defined *a priori*, these must be derived in connection with the identification of the main processes.

Subject to the identified processes or criteria, a catalogue of suitable measures, which is to be examined and evaluated in the context of the scenario analysis (step 6), is prepared. Additional measures may possibly be identified during the scenario analysis and can later be added to the list of suitable measures.

Following the results of the analysis, some of the *a priori* defined objectives (step 1) may have to be adapted. As a consequence thereof system boundaries may have to be relocated and relevant input variables be redefined. To limit the spatial extension of the final model, the system constraints must be chosen as narrow as possible. For this purpose, it is necessary to include only the subsystems which have an essential impact on the criteria or the mitigation measures planned (Meirlaen and Vanrolleghem, 2002).

The further model set up is based on the definition of interfaces and interactions between the considered components of the system. At this point, one should also critically reflect on whether the analysis actually requires an integrated model. Possibly, an integral analysis of the system does not yield any additional information compared to the application of traditional model concepts based on a separate analysis of each subsystem. Such an approach may also be adequate for the assessment of the measures and, compared to an integrated study, provides the advantage that it is significantly easier to manage.

Step 3 - Modelling approaches and data demand

With the completion of the second step, the system should have been reduced to a manageable complexity considering only the significant impacts and processes. The reduced system represents the basis for the selection of appropriate modelling approaches that describe the identified significant processes and interactions of the system. At this stage, an important task is to analyse whether the available modelling approaches meet the requirements or if the selected approaches have to be adapted to suit the task at hand (in the worst case, some approaches may have to be redefined or newly developed). Rauch *et al.* (1998) discuss how the defined objectives have an impact on the selection of modelling approaches.

Beyond the modelling approaches, an adequate amount of data is essential to define the model structure and to identify the model parameters. Normally, the data for the subsystems will be available with different quality and on different (temporal) scales. The required quality of the data is determined by the selected modelling approaches and the defined processes respectively. The more detailed the modelling approach describes the physical interrelationships, the higher the data requirements are. Vanrolleghem *et al.* (1999) give indications for the conception of measuring campaigns that produce data of adequate quality for integrated modelling. Fletcher and Deletic (2006) formulate general requirements on data from a view of integrated urban wastewater management.

If a discrepancy between the selected approaches and the available data arises, in principle, two solutions are possible:

- Conduction of additional measuring campaigns to close the data gap,
- or selection of altered, less sophisticated modelling approaches for which the available data base is adequate (Willems, 2004).

The balance of the processes to be considered, the adequate modelling approaches, and the available data is usually limited by the resources (time and money) available for the study. The set up of the integrated model and the entire study can be significantly affected by these two-way interconnections (Schütze and Alex, 2004). In addition to the set up of the elementary model structure, the interfaces between the different subsystems have to be described in form and content. Therefore, attention should be paid to the specific characteristics of the different fractions of the considered substances. If necessary, the transformation of the regarded substances has to be defined at the interfaces between different subsystems (Volcke *et al.*, 2006). Furthermore, different temporal scales may have to be coordinated between the subsystems. In general, it can be stated that it is important for the development of an integrated model to reduce the complexity and the size of the model as far as possible („As detailed as necessary, as simple as possible“).

Step 4 - Analysis of model and data

On the one hand this step includes the quality assurance of the data (available *a priori* or collected during the study) and, on the other hand, it covers the analysis of the integrated model and the sub-models. In particular, the model analysis covers the aspects of model robustness and verification of the interfaces’ functionality. In addition, the uncertainties associated with the data used and the integrated model built should be analysed and quantified, if feasible.

Data received by measurements are generally limited by the intrinsic ability of each method to detect a given parameter. These limitations are dependent on the instruments and the method used, as well as the characteristic of the sample (type, size, matrix) and the human element. In this context, it is also important to keep in mind that the “true” value of a parameter to be measured is in fact never known for what each measured value is associated with a certain level of uncertainty.

Beyond the data required for model set up and for the hydraulic calibration and validation process water quality data is usually of major interest in the context of integrated modelling. One should acknowledge the fact that quality data without corresponding quantity data is unusable. Quality assurance of quantitative data is already an ambitious task; however, to guarantee a good quality of water quality data is an even more demanding challenge.

Conversion processes of water quality constituents are often dominated by dilution and mixing in the recipient, and very often the regarded substance is not completely distributed steadily over the whole cross section. As a consequence, the impacts of these effects need to be known and considered in the quality assurance process. These circumstances make it sometimes extremely difficult to detect a trend and to distinguish between a detected trend and other phenomena, e.g. effects caused by the sensor used (drift, shift). Moreover, the reference method is also afflicted with uncertainties (Bertrand-Krajewski, 2004). These must be considered in the data evaluation. Only a meticulous analysis results in confidence intervals within which all measurements have the same information content.

In general, various methods and tools for carrying out a quality assurance of measured data are available. In practice, however, these methodologies are only rarely used and even fewer fully automatic methods are applied. The following topics are of importance:

- Distinction between measurement errors and system alterations
- Detection of long-term trends and temporarily altered conditions
- Distinction between natural variations and anthropogenic impacts

Preliminary simulations should be performed using the model under development (step 3). The simulation results have to be analysed with respect to possible errors (plausibility checks). Primary objectives of the analysis should be the identification of unstable simulation runs as well as erroneous parameter definitions and model structure. Useful indicators include, for example, implausible loads and concentrations in the receiving water or surcharged nodes at high points in the sewer system. Also, the verification of the interfaces' functionality is important at this stage. The interfaces between the sewer system and the WWTP as well as the recipient are a crucial point. Particularly the transformation of the different sets of process variables is problematic and is known as one of the weakest points in integrated modelling (Schütze *et al.*, 2002). Normally, quality models for sewer systems (e.g. SMUSI (Muschalla *et al.*, 2006) or KOSIM (itwh, 2000)) are based on at most two COD-fractions whereas the Activated Sludge Model Nr. 1 (Hence *et al.*, 1986) is based on seven fractions of COD alone. Simulated discharges based on different temporal scales can also become problematic.

Furthermore, "good modelling practice" demands an estimation of the predictive performance of the model. A mathematical model is composed of mathematical equations, input parameters, model parameters, and state variables. In any case, there is a deviation between the model and the reality.

The model input parameters can be a significant source of uncertainty. The estimation of model parameters, e.g. in the context of calibration (see step 5), can result in considerable falsifications of the simulation results if not a thorough evaluation of data quality is conducted to identify obvious measurement errors (Gamerith *et al.*, submitted). Problems of identification and with correlated parameters have to be considered also. Further uncertainties can result from numerical or mathematical errors or inadequate model structure. The quantification of model uncertainty often demands high computational effort (e.g. MonteCarlo simulation). For this reason, the application of uncertainty analysis in the context of integrated modelling is still limited, nevertheless some contributions to this topic can be found in the literature (e.g. (Mannina *et al.*, 2006)

Step 5 - Calibration and validation

In principle, discrepancies between the predicted (simulated) and the real (measured) system behaviour are unavoidable. The reasons for this are complex and multifaceted. On the one hand, the model approaches on which the simulation model is based always represent a simplification of the real physical interrelationships. On the other hand, the model parameters can often not exactly be identified. Hence, the calibration process is a crucial and fundamental component of the model development process.

In this context, calibration (or better the estimation of model parameters) is defined as the determination of model parameters by comparing simulated and monitored (measured) system behaviour. For this purpose, simultaneous measurements of precipitation, discharge, and concentration need to be available at different locations in the system considered. Especially at locations with interactions of different system components (e.g. CSO structures) sufficient measurement data is needed.

In the field of integrated modelling, the estimation of model parameters is normally conducted iteratively. Based on the available data set, the estimate is updated in each iterative step, aiming to minimise the difference between simulated and measured system behaviour. Using suitable quality indicators (e.g. model efficiency coefficient according to Nash and Sutcliffe (1970)), this results in an optimisation problem that can either be solved by trial and error approaches or by using an adequate optimisation technique.

For successful parameter estimation, some preliminary steps must be conducted. The available data has to be splitted into two subsets:

(1) A first set of data for estimating the parameters
(2) The remaining data for validating the model

The first set will be used to calculate the estimates of the parameters; the second data set will be used to verify that the model is able to predict the dynamics of the processes with these parameters. Dealing with such complex systems as in the context of integrated modelling makes it unavoidable to select the parameters to be estimated a priori. Methods based on sensitivity analysis ensure reliable estimation. This also entails the definition of physical or user-defined constraints on the parameters and the proper choice of the initial guesses. If possible, a two-step approach is advantageous. At first, a separate calibration of the different subsystems is performed where possible (e.g. sewer system and WWTP). Secondly, a calibration of the whole system is conducted with a special focus on the systems affected by other sub-systems (e.g. receiving water body). In all steps, the calibration is performed first for the hydrology and hydraulics only and second for the quality processes. Normally, the hydraulics is independent from the quality processes but not vice versa. A broad discussion of this topic can be found e.g. in (Dochain and Vanrolleghem, 2001). A practicable example is described by (Muschalla *et al.*, 2007).

Nevertheless, if no calibration is conducted or a proper parameter estimation is not possible (e.g. due to missing data), qualitative statements can still be derived from integrated models. However, a plausibility check of the parameter set and the simulation results has to be carried out in any case (for example, for the degree of imperviousness in urbanised catchments or a comparison of measured and simulated inflow to the WWTP). Also, a comparison between simulated and observed or reported system behaviour should be carried out (e.g. observed eutrophication of receiving water body or reported frequency of CSO spillages).

Step 6 - Scenario analysis

The mitigation measures to be analysed (step 2 – processes and criteria) have to be implemented in suitable simulation scenarios. Possibly, the selected mitigation measures become more concrete while setting up the simulation model and can be modelled by varying selected model parameters or by adapting the model structure. In addition, the model inputs (dry weather condition and/or rain series) and the simulation periods (event based or long term simulation) have to be defined for each scenario. For the comparison of different mitigation measures/scenarios, an initial state (typically described as base-line or reference scenario) must be defined and simulated. After simulating all scenarios, the simulation results must again be analysed with respect to possible errors (compare step 4).

The scenarios are assessed regarding the defined criteria and objectives (step 2). The different scenarios are compared with the reference scenario based on the defined criteria; however, one can distinguish between an absolute and a relative assessment of the scenarios.

If a detailed calibration is not feasible, it is only possible to conduct a relative comparison between the different scenarios. In this case (no detailed calibration) simulation results can only indicate relative alterations (improvements or deteriorations).

A detailed calibration that is carried out successfully allows the comparison with the reference scenario regarding absolute limit values (e.g. maximum concentrations in the river).

If the defined objectives are not yet accomplished (according to the analysed scenarios), new mitigation measures have to be defined. Before they can be implemented into new simulation scenarios, it has to be verified whether the previously applied modelling approach allows an adequate description of the ‘new’ measures (steps 3 and 4). If this is not the case, the selection of another modelling approach and a following model analysis (step 4) and calibration may become necessary (step 5).

Step 7 - Documentation

The documentation of an integrated simulation study should be detailed enough for relating to all aspects/tasks ex post and for reproducing the simulation results. The documentation should comprise of at least the following aspects: objectives of the study, approach, selected modelling approaches (including explanatory statements), used software package(s) (and version number), all relevant operation and process data of the system analysed, final simulation model(s), list of used parameter sets (explanation, if chosen parameters significantly differ from usual parameter ranges), relevant results of data evaluation (e.g. mass balance) and calibration and validation results. All conducted analyses (e.g. scenario analysis) should also be documented in a traceable manner. For the documentation, it is advantageous to refer to the work steps described in this paper.

SUMMARY AND CONCLUSIONS

As indicated in the introduction of this paper, an important paradigm shift in the definition of performance indicators for urban wastewater systems has occurred in legislation and practice in recent years. More and more, the integrated assessment of urban wastewater systems attracts notice to water resources management in general and the management of urban wastewater systems in particular. Also, a number of guideline documents, manuals and directives have become effective (e.g. the Urban Pollution Management Manual in UK (FWR, 1994; FWR, 1998), the Guideline M3 in Germany (BWK, 2001; BWK, 2003), the Swiss STORM guideline (VSA, 2007) or the EU-Water Framework Directive (Council of the European Communities, 2000)), however, a substantial guidance for integrated modelling is still missing. What makes this even more astonishing is that integrated modelling is one of the crucial points in the context of integrated assessment of urban wastewater systems. The HSG Guideline Document for Modelling of Integrated Urban Wastewater Systems is believed to contribute to close this gap. Further information about the HSG group in general and the guideline document in particular can be found at www.hsgsim.org.

This paper and the underlying guideline document summarise and describe the experience of the Central European Simulation Research Group (HSG) in the field of integrated modelling of urban wastewater systems. In the last ten years, several contributions of group members to this topic have been published in conference proceedings, journal papers, and books. In addition, several PhD theses on this topic have successfully been concluded. Quite a few of these publications represent a valuable supplementation to the described guideline document. In table 1, a selection of these contributions is summarised as reference for the reader.

Table 1. Supplementing documents

Reference	Content
(Erbe *et al.*, 2002)	Integrated modelling as an analytical and optimisation tool for urban watershed management
(Frehmann *et al.*, 2002)	Effects of real time control of sewer systems on treatment plant performance and receiving water quality
(Muschalla, 2008)	Optimisation of integrated urban wastewater systems
(Peters *et al.*, 2007)	Potentials of real time control, stormwater infiltration and urine separation to minimize river impacts
(Schütze *et al.*, 2002)	Modelling, simulation and control of urban wastewater systems
(Solvi, 2007)	Modelling the river system in urban areas in view of the EU WFD
(Wiese *et al.*, 2005)	Integrated real-time control for a sequencing batch reactor plant and a combined sewer system

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REFERENCES

Bertrand-Krajewski, J.L. (2004). TSS Concentration in Sewers Estimated from Turbidity Measurements by Means of Linear Regression Accounting for Uncertainties in Both Variables. Water Science & Technology **50**(11), 81-88.

Butler, D. and Schütze, M. (2005). Integrating Simulation Models with a View to Optimal Control of Urban Wastewater Systems. Environmental Modelling & Software **20**(4), 415-426.

BWK (2001). Merkblatt 3. Ableitungen von immissionsorientierten Anforderungen an Misch- und Niederschlagswassereinleitungen unter Berücksichtigung örtlicher Verhältnisse. Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau e. V., Düsseldorf.

BWK (2003). Begleitband zu dem BWK-Merkblatt 3. Ableitungen Ableitungen von immissionsorientierten Anforderungen an Misch- und Niederschlagswassereinleitungen unter Berücksichtigung örtlicher Verhältnisse. Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau e. V., Düsseldorf.

Council of the European Communities (2000). Directive 2000/60/EC of the Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. Official Journal L327 1.

Dochain, D. and Vanrolleghem, P.A. (2001). Dynamical Modelling and Estimation in Wastewater Treatment Processes. IWA Publishing, London.

Erbe, V., Risholt, L.P., Schilling, W. and Londong, J. (2002). Integrated Modelling for Analysis and Optimisation of Wastewater Systems - the Odenthal Case. Urban Water **4**(1), 63-71.

Fletcher, T. and Deletic, A., Eds. (2007). Data Requirements for Integrated Urban Water Management. Urban Water Series - UNESCO-IHP, Routledge, UK.

Frehmann, T., Niemann, A., Ustohal, P. and Geiger, W.F. (2002). Effects of Real Time Control of Sewer Systems on Treatment Plant Performance and Receiving Water Quality Water Science & Technology **45**(3), 229–237

FWR (1994). Urban Pollution Management Manual, a Planning Guide for the Management of Urban Wastewater Discharges During Wet Water. First Edition. Foundation for Water Research, Marlow.

FWR (1998). Urban Pollution Management Manual, a Planning Guide for the Management of Urban Wastewater Discharges During Wet Water. Second Edition. Foundation for Water Research, Marlow.

Gamerith, V., Muschalla, D., Schröter, K., Könemann, P. and Gruber, G. (submitted). Application of Multi-Objective Auto-Calibration Schemes in Pollution Load Modelling Based on High-Resolution Calibration Data Sets. Proc. 11th International Conference on Urban Drainage, Edinburgh, Scotland.

Hence, M., Grady, C., Gujer, W., Marais, G. and Matsuo, T. (1986). Activated Sludge Model No. 1. IAWPRC Task Group on Mathematical Modelling for Design and Operation of Biological Wastewater Treatment. IAWPRC, London.

itwh (2000). Kosim 6.2 Anwenderhandbuch. Institut für technisch-wissenschaftliche Hydrologie, Hannover.

Lijklema, L., Tyson, J.M. and Le Souef, A.S., Eds. (1993). Interurba, Interactions between Sewers, Treatment Plants and Receiving Waters in Urban Areas. Proceedings of Interurba '92. Water Science and Technology. **27**(12).

Mannina, G., Freni, G., Viviani, G., Sægrov, S. and Hafskjold, L.S. (2006). Integrated Urban Water Modelling with Uncertainty Analysis. Water Science & Technology **54**(6-7), 379–386.

Meirlaen, J. and Vanrolleghem, P.A. (2002). Model Reduction through Boundary Relocation to Facilitate Real-Time Control Optimisation in the Integrated Urban Wastewater System. Water Science and Technology **45**(4-5), 373-381.

Muschalla, D. (2008). Optimization of Integrated Urban Water Systems Using Multi-Objective Evolution Strategies. Urban Water Journal **5**(1), 57-65.

Muschalla, D., Gruber, G., Gamerith, V., Schneider, S. and Schröter, K. (2007): Sewer Modelling Based on Highly Distributed Calibration Data Sets and Multi-Objective Auto-Calibration Schemes. Proc. 5th International Conference on Sewer Processes and Networks, Delft, Netherlands.

Muschalla, D., Ostrowski, M.W., Pereira, C. and Schneider, S. (2006). Dokumentation des Schmutzfrachtmodells Smusi Version 5.0. Institut für Wasserbau und Wasserwirtschaft, Technische Universität Darmstadt, Darmstadt.

Nash, J.E. and Sutcliffe, J.V. (1970). River Flow Forecasting through Conceptual Models Part I -- a Discussion of Principles. Journal of Hydrology **10**(3), 282-290.

Peters, C., Keller, S., Sieker, H. and Jekel, M. (2007). Potentials of Real Time Control, Stormwater Infiltration and Urine Separation to Minimize River Impacts: Dynamic Long Term Simulation of Sewer Network, Pumping Stations, Pressure Pipes and Waste Water Treatment Plant. Water Science & Technology **56**(10), 1-10.

Rauch, W., Aalderink, H., Krebs, P., Schilling, W. and Vanrolleghem, P. (1998). Requirements for Integrated Wastewater Models - Driven by Receiving Water Objectives. Water Science and Technology **38**(11), 97-104.

Rauch, W. and Harremoës, P. (1996). The Importance of the Treatment Plant Performance During Rain to Acute Water Pollution. Water Science and Technology **34**(3-4), 1-8.

Schütze, M. and Alex, J. (2004): Suitable Integrated Modelling - Based on Simplified Models. In: P. Krebs and L. Fuchs (eds.). Proc. Sixth International Conference on Urban Drainage Modelling, Dresden, Germany.

Schütze, M., Butler, D. and Beck, M.B. (2002). Modelling, Simulation and Control of Urban Wastewater Systems. Springer, London.

Solvi, A.-M. (2007). Modelling the Sewer-Treatment-Urban River System in View of the Eu Water Framework Directive. BIOMATH, Department of Applied Mathematics, Biometrics and Process Control PhD thesis. Ghent University, Belgium.

Vanrolleghem, P.A., Schilling, W., Rauch, W., Krebs, P. and Aalderink, H. (1999). Setting up Measuring Campaigns for Integrated Wastewater Modelling. Water Science & Technology **39**(4), 257-268.

Volcke, E.I.P., Van Loosdrecht, M.C.M. and Vanrolleghem, P.A. (2006). Continuity-Based Model Interfacing for Plant-Wide Simulation: A General Approach. Water Research **40**(15), 2817-2828.

VSA (2007). Abwassereinleitungen in Gewässer bei Regenwetter (Storm) – Richtlinie für die konzeptuelle Planung von Massnahmen. Verband Schweizer Abwasser- und Gewässerschutzfachleute, Zürich, Switzerland.

Wiese, J., Simon, J. and Schmitt, T.G. (2005). Integrated Real-Time Control for a Sequencing Batch Reactor Plant and a Combined Sewer System. Water Science & Technology **52**(5), 179–186.

Willems, P. (2004): Parsimonious Pollutant Washoff and Sewer Transport Modelling. Proc. 6th International Conference on Urban Drainage Modelling, Dresden, Germany.