Preface

ABOUT THE IWA DESIGN AND OPERATIONAL UNCERTAINTY TASK GROUP

The International Water Association (IWA) Design and Operations Uncertainty Task Group (DOUT) was formed to develop methodologies that enable the explicit evaluation of variability and uncertainty in model-based design of water resource recovery facilities (WRRF), and model-based analysis of plant operations.

An overview of uncertainty in the treatment plant modelling context was discussed at a workshop (in Mont-Sainte-Anne, Canada) during the 1st IWA/WEF (Water Environment Federation) Wastewater Treatment Modelling seminar (WWTmod2008). This workshop identified knowledge gaps and the requirements for the development of the needed methodologies. Following the workshop, the Task Group established the following set of objectives and set-up several working groups to advance these goals:

- Document how uncertainty and risk are currently handled in wastewater treatment practice by consultants, utilities and regulators.
- Propose a set of terms and definitions relating to uncertainty to be used by wastewater professionals.
- Propose a comprehensive list of the sources of uncertainty for typical project phases and contract delivery mechanisms.
- Document and evaluate existing methods for assessing and evaluating uncertainty in wastewater treatment.
- Identify gaps and inefficiencies in current knowledge and practice related to uncertainty.
- Incorporate uncertainty evaluation methodology knowledge from other fields.
- Present examples of methods already available that can be used to deal with uncertainty and variability.

Uncertainty in Wastewater Treatment Design and Operation: Addressing Current Practices and Future Directions
Editor(s): Evangelia Belia, Lorenzo Benedetti, Bruce Johnson, Sudhir Murthy, Marc Neumann, Peter Vanrolleghem and Stefan Weijers
doi: 10.2166/9781780401034_xv

The working groups were composed of professionals from consulting, utilities, software companies and academia. From its inception the intention was one of ***co-production***, further facilitated through a large number of workshops and working meetings held during national and international conferences. The findings obtained through this process form the cornerstone of this Scientific and Technical Report (STR).

MISSION STATEMENT

The goal of the Task Group was to develop methods for integrating uncertainty analysis into wastewater treatment process simulators in order to facilitate a shift from deterministic (one answer) to probabilistic analysis (likelihood of outcome) of treatment plant design and operation. Such a transition will lead to better management and quantification of the risks/benefits of a specific design or operational strategy. This in turn will provide utilities with more effective, efficient facilities and increase the socio-economic benefits of resource recovery.

In pursuit of these objectives, this STR reviews the state of the art in dealing with uncertainty and variability in wastewater engineering, as well as novel methods and approaches recently developed in academia. The STR examines the feasibility of these novel methods for use in the wastewater sector.

SCOPE

The work presented in the STR, focuses on the entire wastewater treatment plant from influent to effluent. Links to the urban catchment (upstream of the wastewater treatment plant) are also discussed because uncertainties associated with expected developments in the catchment have impacts at the planning stage of plant design. Links to the receiving water body (downstream of the wastewater treatment plant) are also discussed as uncertainties in effluent standards imposed by regulators impact plant design and operation.

Much of the work presented in this STR focuses on biological treatment in the liquid stream as this is one of the principal drivers for initiating this paradigm change in design methodology. However, it is important to note that the methodologies presented are model-independent and applicable to any unit process (e.g., primary settling tank, anaerobic digester, etc.), including external factors, or even within an all-encompassing plant-wide modelling approach.

The Task Group hopes that the concepts and methods presented in this STR will contribute to a more systematic and transparent way of managing uncertainty in WRRF design and operations, which in turn will lead to more cost-effective solutions.

Evangelia Belia, Canada
Lorenzo Benedetti, Croatia
Bruce Johnson, USA
Sudhir Murthy, USA
Marc Neumann, Spain
Peter Vanrolleghem, Canada
Stefan Weijers, Netherlands

Acknowledgements

The Design and Operations Uncertainty Task Group (DOUT) was sponsored by the International Water Association (IWA). We would especially like to thank Michael Dunn, former managing director at IWA Publishing and Paul Reiter, former IWA executive director, as well as Mark Hammond and Niall Cunniffe for guiding us through the publishing effort.

The Task Group was also supported by the Water Environment Federation (WEF) and we would like to thank them for their support.

The Natural Sciences and Engineering Research Council of Canada (NSERC) and Primodal Inc., funded a Collaborative Research and Development grant which supported the development of the STR.

The following organisations provided financial support through the sponsoring of projects:

- Waterschap de Dommel, The Netherlands
- Water Research Foundation, Virginia, USA
- Hampton Roads Sanitation District, Virginia, USA

The doctoral research of Mansour Talebizadeh, co-supervised by Cristina Martín, substantially contributed to the STR.

A special thanks goes to the group of professionals that reviewed our initial draft, for their guidance and comments: Eduardo Ayesa, Damian Dominguez, Krist Gernaey, Joe Husband, Paul Lessard, Doug Lumley, Henrik Melcer, Art Umble and Zhiguo Yuan.

We would also like to thank the DOUT workshop contributors for providing additional insights from the wider water resources field:

Charles Bott
David Clark
Tony Flameling
Tony Jakeman
Mark van Loosdrecht
Holger Maier
Libor Novak
Luk Peeters
Antonio Manuel Moreno Ródenas
Simon Tait
Franz Tscheikner-Gratl
Christian Urich

Ludiwine Clouzot acted as our special editor and helped to form the current version of the STR.

We would like to thank the reviewers of the final version of the STR: John B. Copp, Jeffrey Weiss and Erik U. Lindblom. Their edits and suggestions were invaluable and helped us improve the quality of the STR.

Finally, we would like to extend special recognition to the people that inspired us to embark on this journey:

Bruce Beck
Willi Gujer
Paul Harremoës
Peter Reichert
Stefano Saltelli

Introduction to the Scientific and Technical Report

MOTIVATION AND PROBLEM STATEMENT

Over the past 30 years, mathematical models (usually included in simulators) have been displacing the use of heuristic-based ('rules-of-thumb') guidelines for designing water resources recovery facilities (WRRF). Models unify our knowledge about the treatment processes into a single package that is capable of generating comprehensive portraits of how a design will perform. In addition to their value in WRRF design, these models are increasingly being used to evaluate the effect of proposed modifications to plant operations and control, aimed at improving plant performance. Key reasons for the transition to model-aided design and operations include:

- Models allow for more realistic representation of the complexities introduced by hydraulic regime, reactor configuration and variation in operating modes.
- Models can simulate plant performance under dynamic conditions.
- Models enable the designer to analyse and isolate the impact that individual unit operations have on the performance of the treatment train as a whole.
- Models facilitate the examination of effluent quality sensitivity to specific design assumptions.
- Models allow the designer to efficiently screen alternative designs for those that best meet specific environmental goals such as energy efficiency or minimization of greenhouse emissions.
- Models streamline performance comparison of alternative plant designs by facilitating direct comparisons.
- Models can simulate effluent quality response to transient conditions such as wet weather induced influent loadings and operating strategy.
- Models address the growing consensus amongst wastewater professionals that the quality of performance prediction is a critical component of design and operation.
- Wastewater simulation software is a knowledge capture/communication tool that is constantly being updated to simulate new treatment technologies as they gain acceptance and to improve the simulation of existing processes as their behaviour becomes better understood.

A goal of any treatment plant design project is to provide a facility that can be operated reliably to meet specific treatment objectives at minimal cost. Many alternative designs with varying cost structures, performance and risk profiles might be considered to meet the defined objectives. The designer is tasked with the responsibility of finding an acceptable balance between cost, risk and benefit.

Identifying this balance is hampered by the lack of available protocols for explicit risk and benefit assessment. Traditional design methodologies are based upon guidelines and heuristics that have survived the test of time. However, in their application, the complexities of the treatment process are simplified. For example, the variability in plant flow and influent wastewater load is typically addressed through the use of peaking factors. Uncertainty in the coefficients that determine process efficiency is accounted for through the application of safety factors. Judicious choice of these factors provides for a margin of safety that is supposed to ensure adequate performance.

Process model-based design, in addition to the benefits listed earlier, allows the design engineer to incorporate much more information into the design process and in turn to support a more informative assessment of risk and benefits. The reality though is that under current practice, when engineers are interested in evaluating the robustness of a design, they will often overlay a safety factor approach onto the simulation results to accomplish this. In the absence of a prescribed procedure, each engineer will do this in a way that reflects his/her own experiences and prejudices, resulting in some level of arbitrariness.

This need not be. The power and sophistication of existing treatment plant simulators, combined with the wider availability of real-time data and advancements in statistical and data analysis methods, creates opportunities for quantifying treatment plant performance under a wide range of operating conditions. With properly defined protocols, performance profiles can be generated that enable formulation of probabilistic statements (likelihood) regarding various types of failure. Risk/benefit/cost analyses of multiple design alternatives to support identification of the optimal design can be generated. This can be done with a high level of transparency so that each stakeholder can be better informed of the trade-offs they are asked to accept. This is the long-term goal whose exploration is being initiated with this Scientific and Technical Report (STR).

The primary focus of the STR is to develop a comprehensive, workable, and well documented framework for addressing uncertainty and integrating it into WRRF design and operations optimizations. This includes defining what is meant by uncertainty, identifying where uncertainty arises in a project, how uncertainty fits into predicting the long-term performance of a design, how uncertainty influences the attitudes and thus the decision-making process of various stakeholders, methods that are currently available for addressing uncertainty, and methods that are needed but have yet to be developed.

This STR is envisioned as a reference for utilities, regulators and consultants dealing with uncertainty, opportunity and risk in wastewater treatment. The technical details covered in the STR are fleshed out within a comprehensive and holistic framework. This holistic view extends the discussion beyond those uncertainties directly associated with the application of treatment plant models into other areas that influence the final design. This is done in recognition that the chosen design is shaped by inputs from many different stakeholders, and in acknowledgement that uncertainty arises at many stages of project development and execution. These non-model associated uncertainties are important components of the overall uncertainty that influence project risk.

To clarify this last point, consider that the stakeholders in a project might include the public in general, interest or advocacy groups, facility owners, facility operators, facility users, regulators, planners, engineers, designers and contractors. Each comes to the table with different concepts of project objectives and different perceptions and appetites for risk. To illustrate the need for a holistic approach and the complexities of risk in infrastructure projects, consider the example in Box 0.1.

BOX 0.1 UNCERTAINTY – THE BIGGER PICTURE

An engineer is designing a facility that must meet a defined set of effluent limit guidelines. She may receive certain prescriptive criteria for the design from others. She can apply one of the available treatment plant simulators that will enable her to determine the critical aspects of the configuration and sizing of the treatment tanks. She works up a design and then by doing some sensitivity analysis, determines an envelope of conditions under which the design is expected to meet treatment objectives. In doing the sensitivity analysis, she might incorporate some knowledge she has pertaining to statistical uncertainty in some of the model parameters. She might then do some statistical analysis to determine the probability that conditions outside her envelope will be experienced. Based on the findings, she might develop various iterations on the design until she finds a suitable risk profile. The magnitude of that risk is a function of the variability in the key constituents in the wastewater and the uncertainty of various stoichiometric and kinetic parameters in the simulation software being used.

Now the engineer might have received information for the design basis from a planner. The planner may have focused on current and future land use to make forecasts of flows to the plant. He may have decided that the facility should be designed to handle the flows expected 40 years into the future, at which time he expects the catchment to reach maximum flow. To reach this conclusion, the planner may be applying models that are specific to his discipline. He also faces a different set of uncertainties which also contribute to the risk of the project. Whatever the planner determines may simply end up as a specification to which the design engineer must respond, but without any explanation of the attached risks and uncertainties. As a result, embedded into the design are risks unknown to the engineer.

The regulator is charged with setting effluent limitations. In setting limitations, he is guided by the beneficial uses designated for the receiving stream, the water quality objectives necessary to protect those uses and the waste load allocations that follow from those objectives. The regulatory authority might have its own set of models to consult when considering this problem. And these models come with their own unique sources of uncertainty. Then there is the possibility that in the future, the public demands a change in the beneficial uses, or perhaps a future ecological study determines that the assimilative capacity of the receiving is less than originally thought. This might result in a reduction of a waste load allocation with a concomitant lowering of the effluent limitations. How does one consider this regulator risk?

Finally, there are risks that arise out of the contract delivery methods (e.g., has the owner bid the design and construction phases separately or as a package?). Contract delivery methods allocate project risks in different ways and this will have different impacts at various stages of project development.

STRUCTURE OF THE REPORT

This STR is divided into four sections as shown in Figure 0.1 below. Section I, ‘System understanding’, opens with a general discussion of risk, variability and uncertainty, and identifies how they may influence decisions made at various stages of a project (Chapter 1). This section continues with an assessment of how uncertainty is currently handled in practice (Chapter 2). Reading through Chapter 2 – Current practice, the reader should become aware of the fact that the selection of safety factors and conservative design flow and load values are the most prevalent methods used by engineers currently to account for uncertainty and variability. The section concludes with the benefits of incorporating

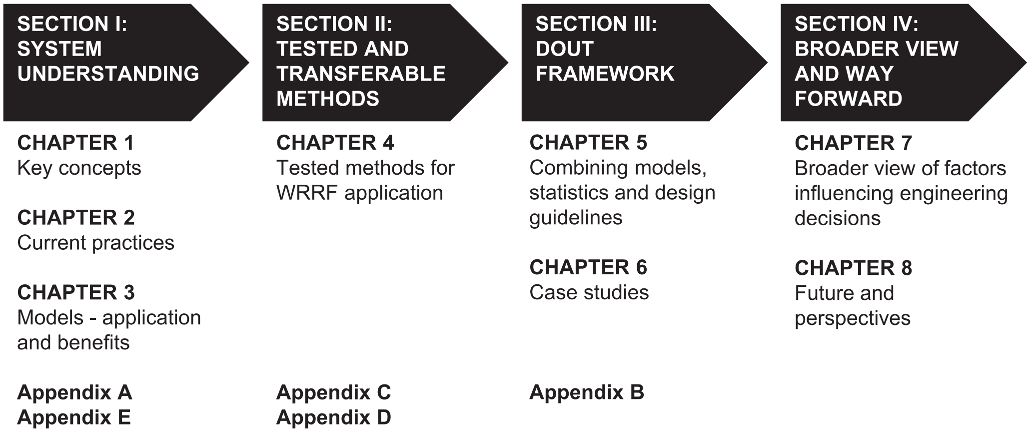

Figure 0.1 The content flow of the STR.

uncertainty analysis in plant design through the use of simulators (Chapter 3). After reading Chapter 3 the reader will have learned about the major sources of uncertainty and variability, how they can be classified in a modelling framework, how practical it is to separate variability from uncertainty and the design parameters that are not amenable to this separation.

Supporting Section I are Appendices A and E. Appendix A includes additional terms and definitions relevant to uncertainty. Appendix E includes examples of engineering practices across selected parts of the world.

Section II, ‘Tested and transferable methods’, focuses on available methods that allow professionals to manage and evaluate ***quantifiable*** uncertainty in explicit ways. It introduces the reader to concepts and methods which are found in the literature and assesses their feasibility for widespread use in wastewater engineering (Chapter 4). A comprehensive up-to-date literature list has been included in Appendix C. Methods developed in other fields and an assessment of their potential for transfer to the wastewater sector can be found in Appendix D.

Section III, ‘DOUT framework’, presents a proposed methodology for combining models, statistics and design guidelines for plant design (Chapter 5). The methodology is applied to the case studies presented in Chapter 6. Chapters 5 and 6 focus on two types of uncertainties: quantifiable and scenario uncertainties. Details on the theory behind the methods described as well as further reading materials, can be found in Appendix B.

The final section, ‘Broader view and way forward’, presents a broader view of the factors influencing engineering decisions (Chapter 7). Chapter 7 discusses the relevance of the contractual environment, the role of the stakeholders and the type of project, and how these play a far greater role in shaping the final outcome of an infrastructure project than is widely acknowledged. Chapter 8 examines possible future ways of dealing with uncertainty and exposes existing challenges, as well as methods available that can already be used by the profession to deal with issues of variability and uncertainty.