Chapter 8

Perspectives

8.1 INTRODUCTION

This chapter seeks to provide a vision on how uncertainty and variability may be handled in the future. We structure the main discussion along the major project phases: regulation, planning, design and operation. A central objective followed by the Task Group has been very technical in nature: 'Replacing the safety factor-based approaches with methods that account for uncertainty in explicit ways'. While investigating the feasibility of such approaches, the Task Group has encountered broader implications. These implications extend far beyond the scope originally set out by the Task Group, which was essentially limited to the explicit inclusion of uncertainty in models describing the physical and bio-chemical processes occurring in treatment plants. In this chapter, a vision integrating the above-mentioned broader implications is developed, by formulating two general objectives and then, listing methods that support these within the different project stages.

The two general objectives that underlie the quest for uncertainty-based methods are:

- **Explicitness**: In current approaches, variability and uncertainty are mostly handled in an implicit way, that is, they are lumped into a safety factor approach. In the future, the Task Group envisions that the sources of uncertainty and variability are made explicit and when possible quantified.
- **Transparency**: In current projects, the rationale of how a design was selected – a process that involves taking decisions under uncertainty – is not always available. A more detailed documentation of decisions in design and optimisation projects as well as in bid selection would improve transparency. This could also be supported by post-project audits to measure the long-term success of a design. A continuous monitoring of loads, capacity and performance of a plant and comparison to planning and design assumptions may also lead to the adoption of alternative service delivery mechanisms or alternative infrastructure configuration and reduce planning biases of future projects.

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8.2 SOCIOECONOMICS AND APPLIED MATHEMATICS

The Task Group believes that a combination of methods from both socioeconomics as well as applied mathematics and statistics will be helpful in realising the two objectives presented in the introduction.

8.2.1 Socioeconomics

The wastewater engineering field has successfully integrated the natural sciences (physics, chemistry, biology). Can we assume a similar integration with socioeconomic sciences in the near future? New approaches such as fore-sighting or multi-attribute decision theory may enhance the toolbox of the engineer and lead to new ways of thinking about infrastructure planning and design. Specific methods that might be used include:

- **Fore-sighting methods**: The adoption of exploration tools such as structured scenario analysis could be especially useful in the early planning phases of wastewater treatment plant projects (Schoemaker, 1995). Spending more time and resources in developing a wide range of potential storylines on how the catchment could develop into the future can improve the credibility of the entire project (e.g., Dominguez *et al.*, 2011) and create better support from all stakeholders.
- **Life-cycle assessment (LCA)**: Including sustainability criteria, for example, through an LCA means that projects can be judged more holistically than in current practice which often focuses on cost−performance criteria (e.g., Corominas *et al.*, 2013; Renou *et al.*, 2008), leading to a more transparent and explicit trade-off between different objectives.
- **Multi-attribute-utility theory**: Such tools (Clemen, 1996) structure decision-making processes in order to reach 'optimal' decisions under multiple criteria (e.g., Reichert *et al.*, 2007) enabling a smoother decision-making process.
- **Benefit−cost−risk approaches**: Making explicit the incentives of different stakeholders and showing how benefits, costs and risks are spread among them can improve overall infrastructure provision.
- **Environmental economics**: Valuing the benefits of preventing pollution, and maintaining ecosystem services go beyond the fulfillment of discharge limits and can make the services provided by wastewater treatment more visible to society.
- **Benchmarking and auditing**: Independent reviews of a city's infrastructure performance and the comparison of results to other cities can identify best practice approaches in view of handling or reducing uncertainties.

8.2.2 Applied mathematics and statistics

For the more detailed technical design stages as well as for the optimisation of operations, a more rigorous use of applied mathematics and statistics offers significant potential for managing both uncertainty and variability in more explicit ways. The increase in computer efficiency results in faster processing of larger problems. This means that one can compute more complex models (computational fluid dynamics, plant-wide models, integrated models including sewer systems and rivers), perform long-term dynamic simulations, apply more sophisticated techniques from systems analysis and artificial intelligence (probabilistic procedures, data mining) or introduce real-time systems for model-based predictive control. All of these advances address various sources of uncertainty and variability. When applying these methods, the wastewater engineer/modeller will need to make a trade-off between rigour and pragmatism in deciding which uncertainties are relevant and need to be considered explicitly in a quantitative fashion, as considering all possible uncertainties is not feasible nor desirable.

8.3 ACCOUNTING FOR UNCERTAINTY IN PROJECTS

The following sections assess how methods from both socioeconomics and applied mathematics can be applied to different stages of wastewater infrastructure development projects.

8.3.1 Regulatory phase

At several instances, the Task Group was confronted with the question: 'What about uncertainty/variability concerning WRRF effluent requirements?' Two main issues are of interest. The first relates to the uncertainty in the derivation of effluent requirements while the second concerns how different effluent permits treat uncertainty and variability when assessing compliance.

Considerable uncertainty is involved in establishing water quality targets to protect a receiving water and as a result their determination often evokes debate. Tools from environmental and ecological economics may offer support to regulators, increase transparency on the benefits of a specific target and facilitate comparisons of infrastructure cost vs. environmental benefits.

Once water quality targets have been determined, they need to be translated into effluent permits. With regard to these effluent permits, the Task Group found considerable differences in their formulation, especially between North America and Europe. In North America, often criteria such as average yearly concentration or maximum monthly concentration are prevalent. When performing model-based design, it is not evident how to define the critical scenarios.

In Europe, percentile-based requirements are used mostly (e.g., 90th percentile day, 50th percentile day). These types of permits account for temporal variability in a straightforward way when using dynamic simulation for design. This permit formulation also facilitates explicit uncertainty evaluation and thus enables more realistic project design.

8.3.2 Planning phase

A successful development of the urban wastewater infrastructure requires continuous interaction with urban planning departments.

Uncertainty is reduced through good relationships between different departments, such as between the infrastructure- and urban planning departments. Then issues can be addressed in a way that leads to integration on questions such as: 'what type of urban development facilitates sustainable wastewater management?' or 'what type of wastewater infrastructure best serves the intended urban development?'

As the life span of a WWTP is in the order of 25 years, uncertainties in the planning phase can be considerable. Scenario analysis is the most widespread tool to deal with these issues (e.g., Dominguez *et al.*, 2009).

The introduction of new infrastructure procurement methods such as service contracts can also be used to change the agent responsible for decisions on planning variables that contain uncertainty. Making explicit how benefits, cost and risk are spread among different stakeholders could improve the formulation of tender requirements and thereby attempt to quantify the uncertainty involved (Flyvbjerg *et al.*, 2003).

8.3.3 Preliminary design

Multi-attribute-utility methods, LCAs and benefit−cost−risk analyses can be ways to make uncertainties explicit and visible at this stage. For the dimensioning of reactors, the Task Group envisages an increased use of complex models for plant-wide design as well as the application of probabilistic procedures.

An example of a desired output of a probabilistic procedure is given in Figure 8.1. The example shows how an engineering consultant may obtain a least-cost design within a 'Design−Build−Operate' bid. The

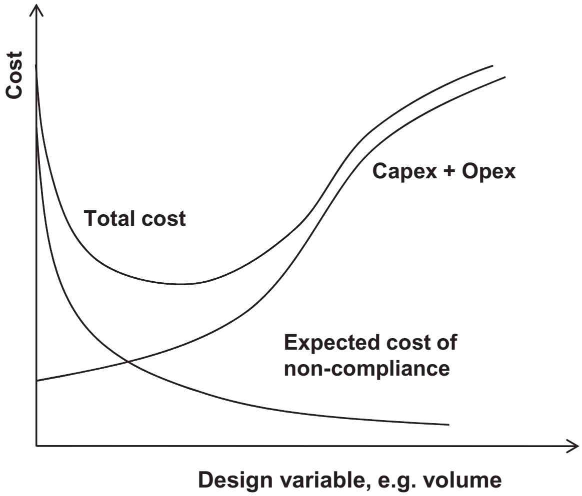

Figure 8.1 Optimisation exercise of an engineering company in a Design-Build-Operate bid. The total cost is the sum of capital and operational expenditure (Capex + Opex) and 'expected' cost of non-compliance (= cost of non-compliance × probability of non-compliance).

company tends to consider capital- and operational expenditure (Capex + Opex) which is with increasing safety (e.g., larger tank volume). Being able to quantify the probability of non-compliance as a function of a design variable enables the estimation of the expected cost of non-compliance as a function of that design variable. In this way, a design with lowest total cost can be identified.

8.3.4 Detailed design

Since unit operations are interconnected, procedures are needed to analyse how the design of a particular unit operation might impact the design of a different unit operation and the overall system performance. The design engineer would benefit from having a tool built upon a knowledge base that would automate a sensitivity analysis that would consider how the individual pieces affect the performance of a whole. The sensitivity analysis would lead to an initial version of the final design that would then require further refinement.

The use of computational fluid dynamics may offer significant potential for optimisation of the flow and transport characteristics of reactors (such as preventing dead-zones and hydraulic short-circuits).

In this design stage, reliability engineering is expected to gain importance in the future for the structural, mechanical and electrical engineering domains to guarantee redundancy in view of robust operations (Sharma *et al.*, 1993; Tung *et al.*, 2006). The design of an Instrumentation Control and Automation (ICA) system can be supported using reliability modelling of actuators (pumps, compressors, diffusers) and sensors.

8.3.5 Operation

The Task Group suggests the introduction of continuous post design-project audits in order to continuously reduce uncertainty. This requires the use of robust sensors for continuous performance assessment and the reporting of non-compliance events in order to correlate failures with their causes: for example, is a non-compliance event due to system size, due to the malfunctioning of a sensor or a controller, due to the inhibition of microorganisms from toxic discharges or the unintended functioning of a process (e.g., foaming or bulking)?

Modern data mining techniques can support the understanding of the plant reliability and the identification of failure events (Duerrenmatt & Gujer, 2012). Process auditing could be done at different time scales: high-frequency data (e.g., 15-minute intervals) to yearly performance measures. Monitoring at high frequency can identify critical reliability issues and improve operational strategies, such as ICA and facilitate the use of model-predictive control. It may also yield insights into the impact of other factors, like human/operator behaviour on plant performance.

The analysis at larger timescales (Dominguez & Gujer, 2006) can uncover issues related to planning assumptions: for example how realistic were the wastewater load projections? Did innovations in technology allow a more efficient use of the installed infrastructure? Did the introduction of new permits render the initial design obsolete? Often, the initial assumptions and the decision process leading to a design are not revisited once the plant is in operation. Performance audits performed across many plants would identify strengths and weaknesses of different procurement strategies and through feeding benchmarking studies help to identify best practices for WWTP planning and design. Such long-term studies could also point to the potential of alternative infrastructure settings and strategies discussed in the following section.

8.4 ALTERNATIVE WAYS OF HANDLING UNCERTAINTY

One of the central objectives of this STR is to propose methods that expose and where possible quantify sources of uncertainty to increase transparency. An alternative to trying to better account and quantify uncertainty is to construct systems that are less vulnerable to the actual sources of uncertainty and variability. These include systems that change when conditions change (adaptive systems) or that are capable of absorbing alternative outcomes (robust systems).

Adaptivity of systems in view of uncertainty can be attained by increasing flexibility, modularity or decentralisation. To increase flexibility, methods (such as 'real options') have been suggested to quantify the value of higher up-front investments that significantly decrease costs for possible expansions that might become necessary in the future (Gersonius *et al.*, 2013). Increasing modularity is another option, where a treatment system is made up of single modules with shorter service lifetimes that can be exchanged more easily. Finally, decentralisation of treatment systems offers another pathway to increase adaptability. For instance, in the case of a one-plant-per-building approach, the uncertainty in the planning stage (such as population growth/shrinkage) and its relevance to the required capacity would be almost completely eliminated. However, the uncertainty linked to performance and the resulting receiving water quality may increase if there is a lack of professional supervision typically present at larger scale plants. An additional disadvantage of small decentralised plants is that, adapting one large plant may be easier than adapting very many small ones, especially when trying to improve effluent water quality, decreasing GHG emissions or implementing resource recovery.

Robustness means that systems are conceived that are not looking to be optimal for an expected outcome, but that work satisfactorily for many possible conditions or future. Robust systems include systems that can switch between different regimes. Such systems would typically require higher implementation of instrumentation, control and automation.

8.5 OUTLOOK

In the ideal approach, most uncertainties are discoverable and can be expressed in some type of mathematical/statistical formulation that can be considered during model simulation. The information needed to achieve this can be extensive. In the end, the practice of probabilistic designs will at best be an approximation of this ideal. In addition, not all uncertainty can be expressed in a statistical sense.

Fore-sighting, such as scenario analysis will necessarily be part of the process. Even so, there will always remain recognised ignorance and total ignorance that by their nature live outside the realm of uncertainty and scenario analysis and can only be observed with hindsight, that is, after having occurred. Nonetheless, by combining the lessons learnt from past plant design and operational experiences with the knowledge and tools that are currently available, significant improvements can be achieved.

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