Summary

In the European Union, the Water Framework Directive enforces a good ecological and chemical status of all surface waters, which is to be accomplished by 2015. Mathematical models provide a valuable tool for guiding the decisions towards meeting the requirements set forth by the Water Framework Directive. In order to meet those requirements, one of the main challenges for the optimization of wastewater treatment plants, today, is the proper evaluation of all important performance indicators such as effluent quality (including priority pollutants) but also energy consumption and greenhouse gas emissions. In order to come to an optimal solution, all relevant aspects need to be considered, as such reducing the uncertainty in the model outcome. It is generally acknowledged that the largest uncertainties are located in the description of influent, hydraulics, gas-liquid mass transfers and primary and secondary settling.

Regardless this importance of the different sub-processes, wastewater treatment plant (WWTP) models, to date, show a clear unbalance in the modelling of the different sub-processes, i.e. the models consist of highly detailed biokinetic models but often lack detail of other critical processes carrying a considerable uncertainty. Improving the balance in the WWTP models basically comes down to move from total ignorance towards quantifiable or scenario uncertainty. Moving away from total ignorance is pursued by incorporating more detail in the important processes. As such, the objective of this work is to include more detail in the sub-process models for influent characterization, primary sedimentation, oxygen transfer (aeration) and energy consumption (aeration blowers and pumps) and showing its impact on the results and calibration of the biokinetic model.

In the second part influent characterisation under dilute circumstances is investigated. A good characterization of the biodegradable substrate entering the plant, especially under storm or rain weather conditions, is required in view of the evaluation of the performance of a WWTP. A first hurdle to be taken towards this characterization is the determination of the yield of heterotrophs, which is likely to change during storm events due to changed wastewater characteristics (e.g. first flush effects and dilution). However, the determination of the yield significantly

extends the length of the analysis procedure, making its application difficult for high frequency measurements or measuring campaigns. A second hurdle, is that low load conditions, due to the dilution effects during or after rain events, hampers the application of respirometric assays for influent fractionation as well. Attempts to improve the measurement have not been successful but indications are given that the evaluation of the assay output based on dynamic models (i.e. increasing the level of detail) will be needed to overcome the encountered hurdles.

In the third part the modelling of primary sedimentation tanks (PST) is investigated. PSTs are often used as a preliminary step in WWTPs and have a significant impact on the subsequent processes. A literature review on primary sedimentation tank models was conducted and it was found that most modelling efforts are based on empirical relations. These empirical models, however, do not succeed in describing the high scatter present in primary sedimentation tank removal efficiency data. A promising approach, to understand the driving forces for this high scatter, is the so-called, phenomenological models, which are models that incorporate more mechanistic knowledge about the process. In this work the phenomenological model of Bachis et al. (2012) has been integrated within a rigorous discretization scheme as proposed by Bürger et al. (2011). The model was further extended with a differentiation between organic and inorganic matter, which is considered to be crucial for the description of the succeeding biological treatment.

For the evaluation of the primary sedimentation tank performance at the WWTP of Eindhoven, data was collected in collaboration with Waterboard The Dommel and comprised routinely collected data as well as data from 3 dedicated measurement campaigns. Modelling the biochemical reactions, by the application of a modified version of ASM2d implemented in the modelling software WEST, enabled to link the unexpected increase of ammonium and phosphate observed during the measurement campaign on May 6, 2014, to the presence of both ordinary heterotrophic and phosphate accumulating organisms in the wastewater. Applying a physical-chemical model implemented in the modelling software PHREEQ-C, supported the hypothesis of the formation of a precipitate (hydroxylapatite) and a consequent removal of phosphate, contributing to the unexpected increase of inorganic suspended solids noticed during the measurement campaign on September 2, 2014. Finally the impact of the sedimentation process on the whole WWTP of Eindhoven was modelled and implemented in the modelling software WEST. It was proven that the primary sedimentation tanks definitely affect the denitrification but may also affect the nitrification.

In the fourth part, aeration and energy consumption is studied. An extensive measurement campaign with off-gas tests at the WWTP of Eindhoven revealed a

high spatial and temporal variability in the oxygen transfer efficiency. Applying this newly gathered system knowledge in the aeration model resulted in an improved fit of the dissolved oxygen concentrations. Moreover, an important consequence of this was that ammonium predictions could be improved by resetting the ammonium half-saturation coefficient for autotrophs to its original value.
Both for aeration energy and pumping energy consumption, a new dynamic model, which includes a detailed description of the system and pump or blower, gave improved predictions of the dynamics compared to the simpler constant average power consumption models currently used.

The study on modelling the sub-processes demonstrated that improving the balance in sub-model details results in improved predictive quality of the model under varying process conditions. As such a simulation methodology should in first instance focus on improving the balance of details in the sub-models rather than force-fitting bio-kinetic parameters. In conclusion, this PhD has considerably extended the model library of less studied parts of the treatment plant allowing for better predictions of effluent quality and energy requirements.